Valuing Decentralized Wastewater Technologies

A Catalog of Benefits, Costs, and Economic Analysis Techniques

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Valuing Decentralized Wastewater Technologies: A Catalog of Benefits, Costs, and Economic Analysis Techniques

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Cover: A trickling filter at a decentralized wastewater management demonstration project run by the City of Austin Water Utility, Austin, Texas. Photograph by Richard Pinkham.

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Preface

This study has its origins in Rocky Mountain Institute's work on decentralized systems in the energy industry. For years now, electric utilities have increasingly turned away from centralized power generation plants and toward "distributed resources" such as small gas turbines, photovoltaics, wind power, fuel cells, and demand management. This has occurred because of a variety of economic benefits of distributed resources relative to large, conventional plants. Rocky Mountain Institute's major report, *Small Is Profitable: The Hidden Economic Benefits of Making Electrical Resources the Right Size* (Lovins et al. 2002), released as a propriety research report in the late 1990s and made publicly available in 2002, reveals the breadth and value of the benefits available from distributed electrical resources. It also shows that experience in centralized management of decentralized systems is rapidly increasing in the energy industry, and techniques for the valuation of the benefits of decentralized systems are becoming available.

The energy and wastewater industries are markedly different. The former is overwhelming privately owned, the latter overwhelmingly publicly owned. The nature of the service provided differs substantially as well. Most importantly, while electrons are an invisible and fungible commodity that can be transported through a regional "grid," wastewater is a highly physical product that can only be manipulated on much more local scale—even the largest metropolitan wastewater systems are much smaller in geographic extent than the sub-national electric power grids.

Nonetheless, many issues and valuation techniques from the electric power industry have important analogs in the wastewater management field. Thus, this report borrows from and builds on the work of Rocky Mountain Institute and others to identify and evaluate differences between "decentralized" and "centralized" approaches to the provision of utility services. It goes far beyond the energy industry analogs, of course, to encompass many issues and opportunities unique to wastewater systems.

The purpose of this report is to present a "catalog" of the economic advantages and disadvantages of decentralized wastewater systems *relative to* larger scale solutions, in order to inform wastewater facility planning and assist communities in making better choices among their many technology options. To this end, this study attempts:

- to compile and summarize what is known about the comparative benefits and costs of various aspects of centralized and decentralized systems; and
- to reveal and discuss the many issues that should be addressed when site-specific wastewater facility plans are prepared, as an annotated "check-list" that will help engineers, planners, and other professionals facilitate a more informed discussion of the advantages and disadvantages of various system options for the communities they serve.

It is important to understand as well what this study is *not*:

- It is not an endorsement of either decentralized or centralized systems as economically superior in a generic sense. The relative costs and benefits of different wastewater systems can only be properly compared for a specific situation for a specific community. This analysis must be performed holistically, taking into account the full range of issues—issues that will vary substantially from place to place and time to time.
- It is not a comparison of the public and environmental health efficacy of different technologies. While some key issues in efficacy are noted, it is assumed that the technologies chosen for comparison in any wastewater facility planning process must all provide adequate health and environmental protection, as determined by regulations or good engineering practice. The question then becomes which option provides that protection at the least total social cost.

- It is not a manual for wastewater facility planning.
- It is not a cookbook for benefit-cost analysis.

This is a research study. Its intended audience includes engineers, economists, planners, and policy makers interested in both the broad issues and the intricacies of the economics of wastewater systems. It will assist those who prepare wastewater facility plans and associated cost and economic analyses. Its level of detail and its presentation format are not targeted toward the general public, though many citizens and community leaders who are presently immersed in a wastewater facility planning process will find the discussions here of interest.

This study is intended to help "level the playing field" in the analysis of centralized and decentralized options for providing wastewater services. We attempt to be even-handed in pointing out potential advantages and disadvantages of both conventional centralized systems and decentralized options. However, the reader should realize that the authors are much more expert in decentralized than centralized wastewater systems. We have looked at decentralized systems *relative to* what we knew and have come to know about centralized systems. Looking at the comparison the other way (as most wastewater professionals do, being more familiar with centralized systems), some readers may find we have missed or minimized important advantages of centralized wastewater systems over decentralized systems. We trust most consultants are amply trained to point out any such omissions to the communities they serve. Our hope is that this work will help wastewater professionals better understand the many benefits of decentralized wastewater systems, as well as their costs and uncertainties, so that decentralized and centralized options can be fairly compared.

This report considers opportunities to apply decentralized wastewater systems beyond the usual applications to small-town and rural communities. At times, we touch on some rather revolutionary notions about the overall architecture of urban/suburban wastewater systems, and by implication other water-related systems. Our findings lead us to believe that the optimal architecture of wastewater systems should be much more mixed than commonly encountered today. Tomorrow's systems will often include decentralized wastewater technologies in "polyculture" with small and large conventional systems. Thus our emphasis should not be seen as "centralized versus decentralized"; rather, we wish to encourage systems that integrate technologies to take advantage of the best features of wastewater options across the full range of scale, with the solutions for each community or region depending upon its specific conditions and needs.

In some places we introduce evaluation concepts that have not yet been applied to wastewater systems other than in theory. But we include them because we believe they could prove very useful to analysis of wastewater options for all types of communities.

Research for this report included an extensive literature review. We discovered that many of the economic issues raised herein have been insufficiently researched and documented, particularly in the academic literature and mainstream industry periodicals. Some are addressed in the "gray literature" of project, program, and topical reports by government agencies, consulting firms, and non-profit organizations. We have incorporated the academic, industry, and gray literature as appropriate and according to quality. In many cases, however, empirical data—whether quantitative or qualitative—is lacking, and we have had to rely on articulating the apparent logic, as best we can discern it, of how a particular issue applies across the spectrum of wastewater system scale.

A report of this scope often raises as many questions as it answers. Thus we end this preface with a request to the reader: we need and solicit your help to improve this work. Please send your criticisms, comments, suggestions, references, contacts, and any additional concepts or evidence bearing on the economic comparison of decentralized and centralized wastewater systems to the primary author at the address below. Only by enlisting the distributed knowledge of the many emerging experts in the planning of innovative wastewater systems can we hope to advance the state of the art as quickly as its importance deserves.

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The National Decentralized Water Resources Capacity Development Project (NDWRCDP) provided funding for a related project that developed case studies of community decision making for wastewater systems. We are grateful for the NDWRCDP's support of that project and for its permission to use material from that project's case study report in this document.

This report borrows both concepts and text from *Small Is Profitable: The Hidden Economic Benefits of Making Electrical Resources the Right Size,* a Rocky Mountain Institute report prepared with grants from the Shell Foundation, The Energy Foundation, and The Pew Charitable Trusts—support which RMI gratefully acknowledges.

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All the organizations and staff involved in this report owe a debt of gratitude to an eight-member project advisory panel that participated in a kick-off workshop to scope the project, provided ideas and assistance along the way, and reviewed and commented on a draft report. The panel consisted of Damann Anderson, Scott Drake, Juli Beth Hinds, Valerie Nelson, Robert Ori, Bob Raucher, Malcolm Steeves, and George Tchobanoglous. Also, Bob Wilkinson participated in the workshop and supported this work during his tenure as director of Rocky Mountain Institute's water research and consulting activities.

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Acronyms

$A	Australian dollars
ASR	Aquifer Storage And Recharge
AST	Advanced Secondary Treatment
ATU	Aerobic Treatment Unit
BEA	Bureau of Economic Analysis
BLS	Bureau of Labor Statistics
BOD	Biological Oxygen Demand
CERCLA	Comprehensive Environmental Response, Compensation and Liability Act
cfs	cubic feet per second
COSMO	Costs of Onsite Management Options (software)
CVM	Contingent Valuation Method
CWMP	Comprehensive Wastewater Management Plan
DEP	Department of Environmental Protection
DU	Dwelling Unit
DSM	Demand Side Management
DWM	Decentralized Wastewater Management
ENR	Engineering News Record
EPA	Environmental Protection Agency
EPRI	Electric Power Research Institute
FTE	Full Time Equivalent
GIS	Geographic Information Systems
GPD	Gallons Per Day
I/A	Innovative/Alternative
I/E	Infiltration/Exfiltration
I/I	Infiltration and Inflow
IMPLAN	IMPact analysis for PLANning (software)
I-O	Input-Output
kg	kilogram
kW-y	Kilowatt per year
LCA	Life Cycle Assessment
LULU	Locally Unwanted Land Use
m^3	cubic meter

MAWSS	Mobile Area Water and Sewer Service
MBR	Membrane Bioreactor
MGD	Million Gallons per Day
mg/l	milligrams per liter
MWRA	Massachusetts Water Resources Authority
N	Nitrogen
NDWRCDP	National Decentralized Water Resources Capacity Development Project
NPDES	National Pollution Discharge Elimination System
O&M	Operation and Maintenance
OWNRS	Onsite Wastewater Nutrient Reduction System
P	Phosphorus
PE	Person Equivalent
POTW	Publicly Owned Treatment Works
PV	Photovoltaic
RBC	Rotating Biological Contactor
REMI	Regional Economic Models, Inc.
RIMS	Regional Industrial Multiplier System
RME	Responsible Management Entity
RMI	Rocky Mountain Institute
RP	Revealed Preference
SAF	Submerged Aerated Filter
SCADA	Supervisory Control and Data Acquisition
SP	Stated Preference
SRF	State Revolving loan Fund
SSO	Sanitary Sewer Overflow
STEG	Septic Tank Effluent Gravity
STEP	Septic Tank Effluent Pump (or) Pressure(ized)
STP	Sewage Treatment Plant
SWRF	Satellite Water Reclamation Facility
TMDL	Total Maximum Daily Load
TMF	Technical, Managerial, and Financial
TSS	Total Suspended Solids
UV	Ultraviolet
VSAT	Vulnerability Self Assessment Tool
WAWTTAR	Water and Wastewater Treatment Technologies Appropriate for Reuse (software)

WSAS	Wastewater Soil Absorption System
WTA	Willingness To Accept compensation
WTP	Willingness To Pay
WWTP	Wastewater Treatment Plant

Executive summary

Objective

This report presents a "catalog" of the economic advantages and disadvantages of decentralized wastewater systems *relative to* larger scale, centralized solutions.[1] It also discusses techniques that can be used to place economic values on the many impacts, positive and negative, brought about by a community's choice of wastewater system scale.

The immediate objective of this report is to inform wastewater facility planning and assist communities in making better choices among their many technology options. Its ultimate purpose is to support local efforts throughout the country to manage water quality, improve environmental conditions, and safeguard public health through improved wastewater systems. The report provides information and techniques to help communities save financial resources and improve infrastructure planning and decision making through more complete analysis of technological options across a fuller range of scale. Users of this report will be able to make better qualitative and quantitative economic comparisons between centralized and decentralized wastewater system options. They will also see that centralized and decentralized options can be integrated, allowing a community to take advantage of the best features of each approach to the provision of wastewater services.

Context

The premise of this report is that communities need whole-system, lifecycle analysis of their wastewater system choices to make the right decisions. This means that all costs and benefits of each option must be taken into account, inside and outside the conventional bounds of infrastructure systems, and from initial capital investments through operation and maintenance to eventual rehabilitation or replacement of an aged system.

The intent of the catalog is to assist what is conventionally called "wastewater facility planning" by making it more comprehensive and representative of whole-system costs and benefits. However, wastewater facility planning as conventionally practiced is too narrow in scope. Too often it does not address the full range of implications of wastewater decisions, and too often it gives decentralized options inadequate consideration. Therefore, this report urges that the practice of facility planning be expanded. The report often uses a different term, *integrated wastewater planning*, to indicate the kind of comprehensive planning and economic analysis communities need.

This report can help "level the playing field" in the analysis of centralized and decentralized options for providing wastewater services. It attempts to be even-handed in pointing out potential advantages and disadvantages of both conventional centralized systems and decentralized options. However, the discussions in this report tend to emphasize decentralization benefits more than decentralization costs. Most engineers and other professionals in the wastewater planning field are more familiar with economies of scale in wastewater system (unit costs decrease as capacity increases), and many do not realize some of the diseconomies of scale (unit costs increase as capacity increases) that occur. Many do not fully understand the many benefits decentralized systems can provide.

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[1] Decentralized wastewater systems are defined as "systems that collect, treat and reuse or dispose of wastewater at or near its point of generation (Crites and Tchobanoglous 1998)." They include single-home onsite systems and cluster systems that may serve many hundred of homes (or equivalent flows). Centralized systems are those that serve entire communities or multiple communities.

Methods

This report is based on an extensive review of literature in and relevant to the fields of wastewater facility planning and integrated wastewater planning. Literature addressing the following topics relevant to wastewater system was gathered, reviewed, and synthesized:

- Financial planning and financial risk
- Community and watershed impacts
- Onsite and neighborhood impacts
- Capital and O&M (operation and maintenance) costs
- Integration with other infrastructure
- Management
- Reliability, vulnerability, and resilience

The report begins with an introduction, Part I, that sets the context for integrated wastewater planning. In Part II of the report, the benefit and cost catalog, potential costs and benefits of decentralized systems—*relative to* centralized systems—are identified and discussed. The information is organized according to the topics listed above, and sub-sectioned appropriately. The discussions are based on relevant findings from the literature. Where literature was lacking or not on-target with the comparative objectives of the report, the authors articulate the “logic of scale” for the particular topic. The findings are summarized into three types of cost and benefit items:

- *Decentralization benefit:* Where smaller scale tends to produce a benefit or save on a cost relative to larger scale.
- *Decentralization cost:* Where smaller scale tends to produce a cost relative to larger scale, or fails to obtain a benefit available at larger scale.
- *Decentralization consideration:* Where there is no clear tendency for smaller scale to be beneficial or costly relative to larger scale. Rather, the relative benefits and costs of different scale systems depend very strongly on the specific nature of the situation and the available wastewater options.

Part III discusses the economic valuation techniques.

Results

Table 1-1 lists all the benefits, costs, and considerations identified in this study for each of the topics listed above. It includes an additional topic, “impacts beyond the watershed,” that is briefly reviewed in this report. Key findings are summarized here:

- *Financial planning and financial risk:* The small unit size of decentralized system allows closer matching of capacity to actual growth in demand. Decentralized capacity can be built house-by-house, or cluster-by-cluster, in a “just in time” fashion. This provides a number of important benefits. It moves capital costs of capacity to the future, typically reducing the net present value of a decentralized approach. The result is often a more economical approach than building centralized treatment capacity or extending sewers (depending on many other factors). Spreading out capital costs also typically means that a community needs to incur less debt, compared to the borrowing requirements of a large up-front capital investment in capacity. This can reduce the financing costs for the community. The “build-as-you-go” aspect of decentralized systems also means that if less growth occurs than first predicted, the community is not stuck with overbuilt capacity and a large debt load that must be spread across fewer than expected residents. Making decentralized investments over time also means that a community can easily adjust its technology choices as improved or cheaper technologies become available. Further, expensive nutrient removal technologies can be targeted to only the locations that are nutrient sensitive, as opposed to upgrading treatment of all the community's wastewater at a centralized plant. Some potential financial disadvantages of decentralized systems are that the large number of systems can increase design, permitting, financial, and other transaction costs of a wastewater service strategy. Also, lenders may perceive individual and small wastewater system debt as riskier investments compared to municipal borrowing, so the unit costs of debt may be higher. Decentralization also concentrates the financial risks of individual system failures on individuals or clusters of residents, in contrast to the insurance-like spreading of risks of failure across large numbers of users that centralized systems can provide. For both centralized and decentralized systems, it is very important that financial planning provides for depreciation and eventual replacement of wastewater assets.

- *Community and watershed impacts:* Decentralized options expand the toolbox of growth management strategies available to communities. In particular, small-scale wastewater systems enable cluster-style development, which has many economic, environmental, and social benefits. On the other hand, in communities without adequate planning and zoning in place, decentralized systems can result in costly haphazard growth. Decentralized systems can also help a community avoid unwanted annexation or regional sewer extensions, thus maintaining the community's autonomy and character. In terms of water quality, smaller wastewater systems may have more or fewer negative impacts on the surface water environment than larger systems, depending on many factors. The same is true of risks to public health presented by wastewater systems. Hydrologically, decentralized systems can avoid drawdown of water tables and reductions in stream base flow that can occur because of infiltration and inflow and other alterations to a watershed water budget caused by sewers. Decentralized systems can also address fairness and equity issues in communities: they are less likely to raise questions over the distribution of costs and benefits of wastewater investments, and they avoid the "double-payment" penalty that occurs when sewers replace recently installed onsite systems. Finally, decentralizing infrastructure tends to reduce the economic stakes involved in wastewater planning, which can help avoid breakdown of relationships and trust within a community.

- *Onsite and neighborhood impacts:* While centralized wastewater systems are essentially out of sight and mind for most property owners (excepting payment of sewer bills), onsite and cluster systems require greater awareness and participation, with attendant non-monetary costs. With respect to aesthetic issues such as visual impacts and odors, centralization tends to create substantial impacts on small areas (around treatment plants), while decentralization tends to widely distribute impacts that are individually less significant. Aesthetic impacts can be mitigated through technology and design choices, but this has costs that may affect the relative economics of wastewater options. System scale may affect how a building can be located on a property, or affect other ways the property can be used. This has impacts on property values. In retrofit and repair/replacement situations, upgrading decentralized systems generally requires less disruption to properties and neighborhoods than construction of sewers.

- *Capital and O&M (operation and maintenance) costs:* Smaller systems lose the advantages of economies of scale that are possible in wastewater treatment capital costs and O&M costs. However, smaller systems also avoid diseconomies of scale that are inherent in sewer systems. Given that collection system costs can be 80 percent or more of total systems costs, collection diseconomies of scale can overwhelm treatment economies of scale, resulting in decentralized systems being the more economical choice. However, high effluent standards tend to favor centralization, although it is possible to produce high quality effluent with some decentralized technologies. Some of these technologies, such as small-scale constructed treatment wetlands, may be more land-intensive.

- *Integration with other infrastructure:* By avoiding the capital and operational expenses of large re-distribution networks, decentralized wastewater systems provide opportunities for cost-effective reuse of water at the site and neighborhood scale. However, onsite and cluster systems do not provide the quantities of water necessary for large water users such as industrial facilities and large landscapes, which in some communities will be the most cost-effective application of reclaimed wastewater. Integration of stormwater systems is also possible in some wastewater reuse schemes, typically at medium to larger system scale.

- *Management:* Management activities generally exhibit economies of scale, which can be attained either by centralized systems or "centralized management of decentralized systems." In some cases management requirements for decentralized systems are simpler and less costly than those for centralized systems.
- *Reliability, vulnerability, and resilience:* Wastewater system reliability, vulnerability to natural hazards and inadvertent or deliberate disruption by humans, and resilience once disturbances have occurred, depend on many factors that can vary with or be independent of system scale. On average, the risks and costs of wastewater system failure are probably less for decentralized systems than centralized systems, because the consequences of small, widely distributed failures are limited while the consequences of large, concentrated failures can be severe.
- *Impacts beyond the watershed:* The choice of wastewater system scale may contribute to costs and benefits realized at the county, state, or national levels. However, these broader implications—to subsidies and financial assistance criteria, regulatory costs, job generation, and greenhouse gases—are not well understood.

The report provides a great deal more detail on these and other benefits, costs, and considerations for wastewater systems. Ultimately, this information can enable communities to better understand the implications of their wastewater system choices, and to make decisions that better meet their multi-faceted needs and objectives.

Table 1-1: Decentralization Benefits, Costs, and Considerations

Financial Planning and Financial Risk
Decentralization benefit: By (typically) moving capacity costs to the future, the net present value of costs for decentralized systems is reduced compared to centralized systems of similar or even somewhat higher nominal costs.
Decentralization benefit: Decentralized systems can reduce the net present value of wastewater system costs by deferring or downsizing the need for replacement systems.
Decentralization benefit: Decentralized systems can help extend the useful service life of existing conventional infrastructure.
Decentralization benefit: The small unit size of decentralized systems allows closer matching of growing demand for wastewater capacity; therefore, less money is tied up in overbuilt capacity.
Decentralization benefit: Decentralized systems can shorten project lead time—e.g. the construction period—further reducing the cost of tying up funds unproductively.
Decentralization benefit: In cases when future demand fails to meet expectations, additional scheduled increments of decentralized capacity can be foregone, avoiding the cost of overbuilt centralized capacity.
Decentralization consideration: Because cluster systems tie-up more time and money in permitting and implementation than do conventional onsite systems, developers may favor onsite systems and the potential benefits of cluster systems may be foregone.
Decentralization benefit: The flexibility of decentralized resources allows managers to adjust capital investments continuously and incrementally, more exactly tracking the unfolding future, with continuously available options for modification or exit to avoid trapped equity.
Decentralization benefit: Modular, short-lead-time technologies valuably temporize: they buy time, in a self-reinforcing fashion, to develop and deploy better technologies, learn more, avoid premature decisions, and make better decisions. The faster the technological and institutional change, the greater the turbulence, and the more uncertain are future needs, the more valuable this time-buying ability becomes.
Decentralization benefit: Smaller, quick-to-build units of decentralized wastewater capacity offer flexible options to planners seeking to minimize regret, because capacity can be added or foregone to match actual demand.
Decentralization benefit: Shorter lead-time and smaller size reduce the planning horizon, consequently decreasing the amplification of errors in forecasting demand with the passage of time.
Decentralization benefit: Because decentralized systems often cost less to plan and design than centralized systems, they generate less exposure to lost costs if a plan is turned down by voters or regulators.
Decentralization benefit: Short lead-time units of decentralized wastewater infrastructure expose a utility to the financial costs of construction delays and capital cost escalations far less than large, slower-to-build treatment plants and major collection system expansions.
Decentralization benefit: The low operating costs of many decentralized technologies expose a utility and system users to less financial risk from variation and escalation in energy and other operating costs.
Decentralization benefit: Even when per unit operating costs of decentralized systems are higher, overall system costs may be less susceptible to inflation and other cost escalations when decentralized systems carry less excess capacity than centralized systems.
Decentralization benefit: A decentralized strategy for capacity expansion is less likely to result in sunk costs in older technologies and instead allows for rapid response to technological change.
Decentralization benefit: Decentralized systems may allow upgrades to be focused on a small subset of a community's capacity, saving substantial capital costs.
Decentralization cost: Decentralized systems may increase the transaction costs of upgrading facilities.
Decentralization cost: Decentralization concentrates the direct financial risks (e.g. replacement costs) of system failure or inadequacy on individuals and small groups, in contrast to the insurance-like spreading of these financial risks in centralized and regional systems. This concentration of risk can impose catastrophic costs on users.

Decentralization consideration: Real impacts of failure, exposure to liability for harm to others or to penalties under law, and the financial resources to survive a finding of liability for a wastewater system failure vary in unclear ways with system scale.

Decentralization consideration: Some technologies used in decentralized wastewater systems may allow a project to be reversed and downsized more easily than typical centralized systems, which have a higher proportion of assets in custom-constructed components or buried in the sewer network. However, centralized treatment systems may have greater value for in-situ reuse, and the market for used conventional wastewater treatment plant components is probably stronger than that for used decentralized system components.

Decentralization benefit: Decentralized systems, by spreading costs over time rather than concentrating costs up front, are more likely to not require borrowing, or to require less borrowing, than centralized systems.

Decentralization benefit: By reducing borrowing increments, decentralized systems strain a utility or community's financial resources less, thereby improving its financial indicators, which may lead to better terms on debt (e.g. as a result of better bond ratings).

Decentralization cost: To the extent decentralized systems require a community to increase the number of times it borrows funds, they may increase the "transaction costs" associated with borrowing.

Decentralization cost: To the extent decentralized systems shift borrowing from a community or utility to entities with smaller assets and revenue sources (e.g. individual homeowners for onsite systems, homeowners' associations for cluster systems), lenders may perceive debt as a riskier investment and the cost of debt, for instance, the interest rates, may increase.

Decentralization consideration: Decentralized systems may be more or less eligible than conventional systems for certain grants, low-interest loans, and other alternative financing.

Decentralization consideration: Decentralized systems allow a community to shift project costs and financing costs to developers or private property owners.

Decentralization consideration: Financial planning for any scale of wastewater system must provide for depreciation and replacement of assets.

Community and Watershed Impacts

Decentralization benefit: Decentralized wastewater systems expand the toolbox of strategies to manage growth and promote "smart growth": they can help avoid sewer-induced sprawl and help direct the location and form of growth as desired by the community.

Decentralization cost: In communities without adequate planning, zoning, and other growth management tools in place, decentralized systems can result in haphazard growth and its attendant costs.

Decentralization benefit: Through reduced density or improved site layout (e.g. with cluster development), decentralized systems can help reduce the proportion of impervious surface in a landscape, thereby cutting pollutant loading to surface water bodies and maintaining groundwater recharge.

Decentralization benefit: Smaller systems can help a community resist unwanted annexation or regional sewer extensions, thus maintaining the community's character, independence and control over other services.

Decentralization benefit: Decentralized systems likely keep more money circulating within a local economy—supporting local income and creating local jobs—than centralized or regionalized systems of similar lifecycle cost.

Decentralization benefit: Decentralized systems avoid the hydrologic impacts that centralized collection systems can cause or contribute to. These include lower water tables, drawdown of aquifers, and reductions in stream base flow.

Decentralization consideration: Direct streamflow augmentation from any scale system may be beneficial or detrimental.

Decentralization consideration: Smaller wastewater systems may have a more or less impact than larger systems on surface water chemistry and ecology, and thereby create economic implications for communities, depending on many factors.

Decentralization benefit: Installation and operation of decentralized systems are likely to cause less disturbance to riparian zones than larger sewer systems.

Decentralization consideration: Smaller wastewater systems may generate greater or lesser public health risks than larger systems, depending on regulations, enforcement, technology, design and construction, O&M, and other factors.

Decentralization consideration: Occupational health and safety risks and hazards to the public vary by technology and system scale and should be considered when system choices are made.

Decentralization benefit: Smaller systems are less likely to raise questions over the distribution of their costs and benefits.

Decentralization benefit: Maintaining decentralized systems as permanent solutions avoids the "double payment" problem sewers can create.

Decentralization benefit: Centralization increases the expertise required of system managers and operators, and therefore the compensation required to retain them, perhaps to a point that generates ill will in some small communities.

Decentralization benefit: Decentralizing infrastructure units tends to reduce the political and economic "stakes" involved in a wastewater facility decision. This can reduce community conflict and its associated costs.

Decentralization benefit: By breaking borrowing needs into smaller amounts that occur periodically as a community grows, decentralized systems can help avoid mistrust and rate shock brought on by large borrowing for capacity that will not be fully used for years.

Decentralization benefit: Smaller systems lend themselves to local decisions, enhancing public comprehension and legitimacy.

Onsite and Neighborhood Impacts

Decentralization cost: While centralized wastewater systems are essentially out of sight and mind for most property owners (excepting payment of sewer bills), onsite and cluster systems require greater awareness and participation, with attendant non-monetary costs.

Decentralization benefit: Centralization intensifies undesirable system characteristics that induce public resistance and loss of value for neighboring properties.

Decentralization consideration: Visual impacts of wastewater systems on sites and neighborhoods may occur with any scale system.

Decentralization benefit: Odor control is typically less of a concern with smaller systems.

Decentralization consideration: Both centralized and decentralized systems can be noisy or quiet, depending on the technology chosen.

Decentralization benefit: Decentralization allows for preservation of open space and its attendant values without the costs of unnecessary infrastructure.

Decentralization cost: The greater the degree of decentralization, the greater the limit on development density. Where higher density is desirable, this may result in an inability to maximize property value.

Decentralization benefit: Advanced decentralized systems may allow the development of otherwise undevelopable property, thereby creating or maintaining property value.

Decentralization consideration: Serving areas with decentralized systems rather than sewers can affect the affordability of properties.

Decentralization consideration: System scale may affect how a building or set of buildings can be located on a property, which may impact development costs and property value.

Decentralization consideration: Some wastewater systems may increase the value of the subject property or adjacent properties because of a perception that the system is particularly novel, sustainable, or valuable environmentally.

Decentralization consideration: Decentralized systems displace and constrain other uses of a site to a lesser degree than centralized systems. The cumulative impact of dispersed, lower impacts of decentralized systems in this respect, versus more intense and concentrated opportunity costs of centralized systems, is not clear.

Decentralization benefit: In retrofit and repair/replacement situations, decentralized systems generally require less disruption of properties and neighborhoods.

Capital and O&M Costs

Decentralization cost: Smaller systems miss economies of scale in wastewater treatment systems.

Decentralization cost: Very small wastewater facilities require higher capacity per capita in order to manage variability in hydraulic loads produced per connection.

Decentralization consideration: Smaller systems are more likely to use alternative sewers that do not require extra treatment plant capacity to manage infiltration and inflow loads typical of gravity sewer systems.

Decentralization consideration: Minimum design flow requirements may result in onsite and cluster systems that are underloaded, affecting their ability to function properly.

Decentralization consideration: Decentralization can be used to isolate waste generators that produce high hydraulic or mass loads (e.g., BOD loads of restaurants, hydraulic and pollutant loads of industrial facilities) in order to reduce the capacity and treatment needs such facilities place on public systems.

Decentralization cost: High effluent standards tend to favor centralized treatment.

Decentralization cost: Smaller treatment systems typically require more material per unit of capacity.

Decentralization consideration: As system scale decreases, per unit costs of treatment plant construction typically increase.

Decentralization benefit: Smaller systems avoid diseconomies of scale in wastewater collection systems.

Decentralization benefit: Smaller systems can avoid the high costs of installing large pipes and can take maximum advantage of alternative technologies that cost less to install.

Decentralization benefit: Smaller systems have shorter pipe lengths per connection served.

Decentralization benefit: Smaller systems have a lower ratio of large pipes versus small pipes, thus reducing the use of more expensive large pipes.

Decentralization benefit: Smaller systems may need fewer manholes or none at all.

Decentralization benefit: Smaller systems often have lower requirements for pumps than larger systems.

Decentralization consideration: Land area requirements and siting constraints may favor or disfavor smaller systems.

Decentralization consideration: Smaller systems are more likely to use "off the shelf" technologies, while larger systems tend to require more sophisticated, customized engineering. However, smaller systems may require more sensitivity to site conditions throughout a service area. A decentralized approach may have greater up-front planning costs.

Decentralization consideration: The sum of permit fees paid to entities outside the community may be less or greater for decentralized systems than centralized ones. Transaction costs to obtain permits may push decisions toward more or less decentralization.

Decentralization cost: Because of the large number of treatment units and effluent discharge points inherent in decentralized systems, capital costs of equipment for monitoring equivalent to that undertaken at centralized wastewater treatment plants would be substantially higher.

Decentralization consideration: Depending on the treatment technology chosen, monitoring capital costs per capita may be lower or higher for decentralized systems than for centralized systems.

Decentralization cost: Smaller systems lose economies of scale that are possible in wastewater system operation and maintenance.

Decentralization benefit: Decentralization resulting in different technology choices may dramatically shift the nature and frequency of required O&M activities, in some cases reducing O&M costs below that of a centralized system serving the same area.

Decentralization cost: For a given technology, labor costs exhibit economies of scale; decentralizing that treatment technology will result in increased labor costs per unit of capacity.

Decentralization consideration: Decentralization usually results in different technology choices, which may have lower or higher labor costs per unit of capacity across the whole system than a more centralized system would.

Decentralization consideration: Decreasing treatment plant size for a given technology will tend to lose economies of scale from bulk purchase of chemicals, but many decentralized technologies require no chemicals or less than those required for some centralized systems.

Decentralization consideration: Decentralized systems may require more or less routine parts and materials replacement than centralized systems serving the same population.

Decentralization consideration: Technologies used for decentralized systems tend to generate lower quantities of biosolids or require less biosolids handling. This may reduce the per capita costs of residuals management.

Decentralization cost: Because decentralized treatment systems are dispersed, they probably require more travel for inspection, operation, and maintenance than more centralized systems.

Decentralization consideration: Periodic permit fees and other fees paid to government bodies in order to operate a wastewater system can range from nonexistent to substantial and may or may not be significant on a per capita basis.

Decentralization cost: Because of the large number of treatment units and effluent discharge points inherent in decentralized systems, costs for ongoing monitoring equivalent to that undertaken at centralized wastewater treatment plants are substantially higher.

Decentralization consideration: Depending on the technology chosen, ongoing monitoring costs per capita may be lower or higher for decentralized systems than for centralized systems.

Decentralization consideration: Insurance to cover the costs of repairing or replacing a failed system or system component would constitute an operating cost if chosen, but is only just beginning to be available to wastewater system owners.

Decentralization benefit: To the extent that a sewer system adds to property value, using instead an onsite system results in lower property tax payments.

Decentralization cost: In the specific case of ownership of onsite systems by a private responsible management entity, the onsite system becomes a taxable asset, and the taxes become an additional cost in comparison to a publicly owned sewer system.

Infrastructure Synergies: Benefits of Integration

Decentralization benefit: By avoiding the capital and operational expenses of large re-distribution networks, decentralized wastewater systems provide opportunities for cost-effective reuse of water at the site and neighborhood scale.

Decentralization cost: Onsite and cluster systems do not provide the quantities of water necessary for large water users such as industrial facilities and large landscapes, which in some communities will be the most cost-effective application of wastewater reuse.

Decentralization consideration: Integration of wastewater and stormwater systems can be considered, under particular conditions, across a range of scale.

Decentralization benefit: Decentralized systems allow for closer control of sources contributing to biosolids, which may provide benefits in improved biosolids quality. Further, new approaches to dry or ultra-low-water sanitation systems based on urine/feces separation offer opportunities for improved capture and use of nutrients in human waste.

Decentralization cost: Decentralized systems do not provide the necessary control and scale to cost-effectively produce energy through sewage sludge digestion and combustion of the resulting methane.

Decentralization consideration: Additional opportunities for integration of wastewater and other systems may be favorable for decentralized systems, while others may be more appropriate for centralized systems.

Management

Decentralization consideration: Management activities generally exhibit economies of scale, which can be attained either by centralized systems or "centralized management of decentralized systems." In some cases management requirements for decentralized systems are simpler and less costly than those for centralized systems.

Reliability, Vulnerability, and Resilience

Decentralization consideration: System reliability depends strongly on the inherent reliability of the chosen treatment processes and on proper operation and maintenance—factors that can vary with or be independent of system scale.

Decentralization consideration: As a whole, decentralized systems may be somewhat less vulnerable to natural hazards and deliberate sabotage, but are perhaps more vulnerable to system misuse and inadvertent interference. Much depends on the particular technology, local conditions, and prevention and mitigation measures.

Decentralization consideration: Diversity of treatment units, ease of repair, and other factors may make decentralized systems more resilient than centralized ones, but technology choices and local conditions will affect comparative resilience.

Decentralization benefit: On average, the risks and costs of wastewater system failure are probably less for decentralized systems than centralized systems, because the consequences of small, widely distributed failures are limited while the consequences of large, concentrated failures can be severe.

Impacts Beyond the Watershed

Decentralization consideration: The choice of wastewater system scale may contribute to costs and benefits realized at the county, state, or national levels. However, these broader implications—to subsidies and financial assistance criteria, regulatory costs, job generation, and greenhouse gases—are not well understood.

PART I – INTRODUCTION

1 Objective

This report presents a "catalog" of the economic advantages and disadvantages of decentralized wastewater systems *relative to* larger scale, centralized solutions.[2] It also discusses techniques that can be used to place economic values on the many impacts, positive and negative, brought about by a community's choice of wastewater system scale.

The immediate objective of this report is to inform wastewater facility planning and assist communities in making better choices among their many technology options. Its ultimate purpose is to support local efforts throughout the country to manage water quality, improve environmental conditions, and safeguard public health through improved wastewater systems. The report provides information and techniques to help communities save financial resources and improve infrastructure planning and decision making through more complete analysis of technological options across a fuller range of scale. Users of this report will be able to make better qualitative and quantitative economic comparisons between centralized and decentralized wastewater system options. They will also see that centralized and decentralized options can be integrated, allowing a community to take advantage of the best features of each approach to the provision of wastewater services.

2 Context

The premise of this report is that communities need whole-system, lifecycle analysis of their wastewater system choices to make the right decisions. This means that all costs and benefits of each option must be taken into account, inside and outside the conventional bounds of infrastructure systems, and from initial capital investments through operation and maintenance to eventual rehabilitation or replacement of an aged system.

The intent of the catalog is to assist what is conventionally called "wastewater facility planning" by making it more comprehensive and representative of whole-system costs and benefits. However, wastewater facility planning as conventionally practiced is too narrow in scope. Too often it does not address the full range of implications of wastewater decisions, and too often it gives decentralized options inadequate consideration. Therefore, this report urges that the practice of facility planning be expanded. The report often uses a different term, *integrated wastewater planning*, to indicate the kind of comprehensive planning and economic analysis communities need.

This report can help "level the playing field" in the analysis of centralized and decentralized options for providing wastewater services. It attempts to be even-handed in pointing out potential advantages and disadvantages of both conventional centralized systems and decentralized options. However, the discussions in this report tend to emphasize decentralization benefits more than decentralization costs. Most engineers and other professionals in the wastewater planning field are more familiar with economies of scale in wastewater system (unit costs decrease as capacity increases), and many do not realize some of the diseconomies of scale (unit costs increase as capacity increases) that occur for larger wastewater systems and do not fully understand the many benefits decentralized systems can provide.

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[2] Decentralized wastewater systems are defined as "systems that collect, treat and reuse or dispose of wastewater at or near its point of generation (Crites and Tchobanoglous 1998)." They include single-home onsite systems and cluster systems that may serve many hundred of homes (or equivalent flows). Centralized systems are those that serve entire communities or multiple communities.

3 Shaking the centralized wastewater paradigm

Optimal scale for wastewater systems is not a technical issue, but a matter of community needs and resources. Wastewater can be treated to any existing regulatory standard, indeed to drinking water quality, at a scale ranging from plants that treat the waste of individual homes to ones that serve millions of people.

The conventional wisdom in the lay population and among many professionals in the wastewater field is that centralizing treatment is the best wastewater management strategy for most communities—the most reliable, easiest to manage, and least costly per capita. Septic systems and other decentralized technologies serving small portions of a community are often seen as suitable only in low-density, rural situations, and then only as temporary solutions until such time as local growth allows these areas to be served by sewers and connected to central treatment plants.

This common view, however, is not universally accepted. In a 1997 report to Congress, the U.S. EPA found that adequately managed decentralized systems are a cost-effective and long-term solution for many communities (U.S. Environmental Protection Agency 1997). In the U.S., hundreds if not thousands of dedicated professionals, affiliated with organizations such as the National Decentralized Water Resources Capacity Development Project (a program Congress funds through the EPA), the National Small Flows Clearinghouse, the Consortium of Institutes for Decentralized Wastewater Treatment, and the National Onsite Wastewater Recycling Association work to make communities aware of the role decentralized systems can play and to ensure that such systems are properly designed and managed.

Nor do sanitation experts who serve developing countries universally accept that conventional, centralized wastewater treatment is the standard toward which developing countries should aim. For instance, in a World Bank report on sanitation and disease in the developing world, the authors give this advice:

> Those whose job is to select and design appropriate systems for the collection and treatment of sewage in developing countries must bear in mind that European and North American practices do not represent the zenith of scientific achievement, nor are they the product of a logical and rational design process. Rather, treatment practices in the developed countries are the product of history, a history that started about 100 years ago when little was known about the fundamental physics and chemistry of the subject and when practically no applicable microbiology had been discovered. … These practices are not especially clever, nor logical, nor completely effective—and it is not necessarily what would be done today if these same countries had the chance to start again (Feachem et al. 1983, pp. 63–64).

Why do some question the wisdom of centralizing wastewater treatment? Consider the following problems of centralized wastewater systems:

- *Centralized systems are unaffordable for many small communities.* Too often, conventional centralized systems are simply too expensive for small communities to build. This problem has been particularly acute ever since substantial reductions in federal grants for wastewater systems were made in the late 1980s (Gaeddert 1991; Richard 1990). Small communities have fewer people to support a large wastewater investment. For instance, a conventional wastewater treatment facility (not counting sewers) can cost a community of less than 1,000 people $15,000 to $20,000 per connection, compared to $6,000 per connection for a community of 10,000 or more people (English et al. 1999). If small communities are able to obtain funds and build conventional systems, often the technologies prove to be difficult and costly to maintain given the limited technical and financial capacity of most small communities (Kreissl and Otis 2000).
- *In some places centralized systems have been overbuilt, resulting in crushing debt burdens for citizens.* For instance, Hillsborough County in Florida built a very large sewer system in the expectation of rapid growth. When this growth did not materialize, the high debt load could not be

supported by the populace. The county's credit rating was nearly downgraded to junk bond status, and it struggled financially for years.

- *Sewer systems can dramatically impact the hydrology of watersheds.* Infiltration of ground water into sewers is a substantial problem in many communities across the U.S. Wet weather sewer overflows are a well-known consequence in many places. Another consequence, gaining increasing recognition, is that too much ground water is drained away, robbing streams of base flows. In some places, such as the Ipswich River in Massachusetts, this has contributed to the drying-up of some stream segments (Armstrong et al. 2001; Canfield et al. 1999; Pinkham et al. 2004).
- *Sewers can also leak sewage into streams and ground water.* There is evidence that leaking sewer pipes are a substantial problem in parts of the U.S. A study in Albuquerque, New Mexico concluded that leakage of wastewater from sewer pipes amounted to 10 percent of average daily wastewater flow, or five million gallons per day (reported in Amick and Burgess 2000). In some areas, leaking sewers may be a greater source of ground and surface water contamination across the country than are septic systems (Gerba 1998). In Charlotte County, Florida, water levels in some sewers are known to rise and fall with the tide (Pinkham et al. 2004). Exfiltration (outflow) from sewer pipes is receiving increasing research attention (Amick and Burgess 2000; Ellis and Revit 2002).
- *Centralized systems have a huge backlog of deferred maintenance.* The EPA has determined that the gap between what U.S. cities are spending on maintenance and upgrades of collection and treatment systems (as well as drinking water infrastructure) and what is actually needed amounts to many billions of dollars a year (U.S. Environmental Protection Agency 2002b). It is not at all clear how this gap will be closed, given that massive new federal funding is unlikely, but it is clear that communities cannot generally afford to spend any more than they absolutely have to on new infrastructure when the needs of the existing infrastructure are so great. Thus alternative ways of providing wastewater service in suburban areas are gaining increasing attention.

4 What are decentralized wastewater systems?

Decentralized systems are an alternative to conventional, centralized systems. They may help communities avoid or resolve the problems noted above or address many other issues raised by centralization of wastewater services. An oft-quoted definition of decentralized wastewater systems comes from Crites and Tchobanoglous.

> *Decentralized wastewater systems collect, treat and reuse or dispose of wastewater at or near its point of generation* (1998 p. 2 and Table 1-1, p. 3).

Decentralized systems include *onsite systems* that treat wastewater from individual homes or buildings, and *cluster systems* that treat wastewater from groups of two or more homes. Typically cluster systems serve less than a hundred homes, but they can serve more. The "line" between decentralized and centralized systems becomes vague when some cluster systems are considered. Wastewater professionals make the distinction in several ways:

- *Volume*. Decentralized systems treat "relatively small volumes of water." (U.S. Environmental Protection Agency 1997 p. A-1)
- *Sewer type*. Centralized systems typically use conventional gravity sewers, while cluster systems typically use alternatives such as small-diameter pressurized pipes, small-diameter gravity, and vacuum sewers, often employing on-lot settling tanks and/or grinder pumps before wastewater flows from a lot into the sewer system.
- *Treatment type.* Centralized systems typically use activated-sludge processes, while cluster systems typically use alternatives such as sand filters, trickling filters, etc.

- *Discharge method*. Centralized systems typically discharge treated wastewater to a surface water body. Cluster systems typically discharge treated wastewater by infiltration into soil.
- *Ownership*. Centralized systems are typically publicly owned (thus the common term “POTW”: publicly-owned treatment works), while cluster systems are usually owned by a developer, homeowners’ association, or other private entity.
- *Relative scale*. Centralized systems are intended to serve entire communities or substantial areas of large communities. Cluster systems serve only a portion of a community.

All of these ways of differentiating decentralized systems from centralized systems are imprecise. Probably the most precise is the last—relative scale. The U.S. Environmental Protection Agency, in its 1997 *Report to Congress on Use of Decentralized Wastewater Treatment Systems* (U.S. Environmental Protection Agency 1997 p. A-1) includes this notion in its definition of cluster systems. A cluster system is “a decentralized wastewater collection and treatment system where two or more dwellings, but less than an entire community, is served.” Crites and Tchobanoglous, in their major text on decentralized wastewater systems (1998 p. 2), also use a relative scale criterion, together with proximity to generation, in defining system types:

> Decentralized wastewater management (DWM) may be defined as the collection, treatment, and disposal/reuse of wastewater from individual homes, clusters of homes, isolated communities, industries, or institutional facilities, as well as from portions of existing communities at or near the point of waste generation (Tchobanoglous 1995). Where treatment plants have been built to serve portions of a community, they have often been identified as satellite treatment plants, but are classified as decentralized plants in this text. Centralized wastewater management, on the other hand, consists of conventional or alternative wastewater collection systems (sewers), centralized treatment plants, and disposal/reuse of the treated effluent, usually far from the point of origin.

Figure 4-1, from the EPA’s draft *Handbook for Management of Onsite and Clustered (Decentralized) Wastewater Treatment Systems,* provides a graphical depiction of centralized and decentralized approaches to serving a given area.

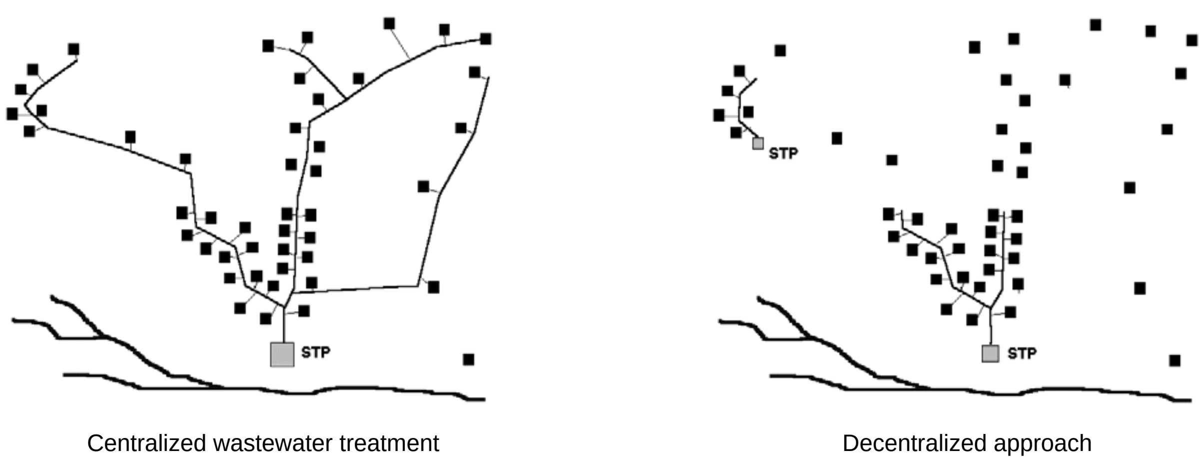

Figure 4-1: Comparison of Centralized and Decentralized Approaches to Wastewater Service. STP indicates a centralized or cluster sewage treatment plant. *Source: Draft Handbook for Management of Onsite and Clustered (Decentralized) Wastewater Treatment Systems (U.S. Environmental Protection Agency 2003a), Figure 1-4.*

To elaborate further on the relative scale notion, it is often useful to talk in terms of *centralization* or *decentralization*. For instance, a cluster system reflects centralization relative to onsite systems. A regional wastewater treatment plant (WWTP) serving multiple municipalities reflects a higher degree of centralization than a number of “centralized” but smaller municipal or community-scale WWTPs.

Relative degrees of centralization or decentralization indicate that there is a continuum of wastewater system scale. Figure 4-1 below illustrates this continuum in reference to a variety of descriptors of scale:

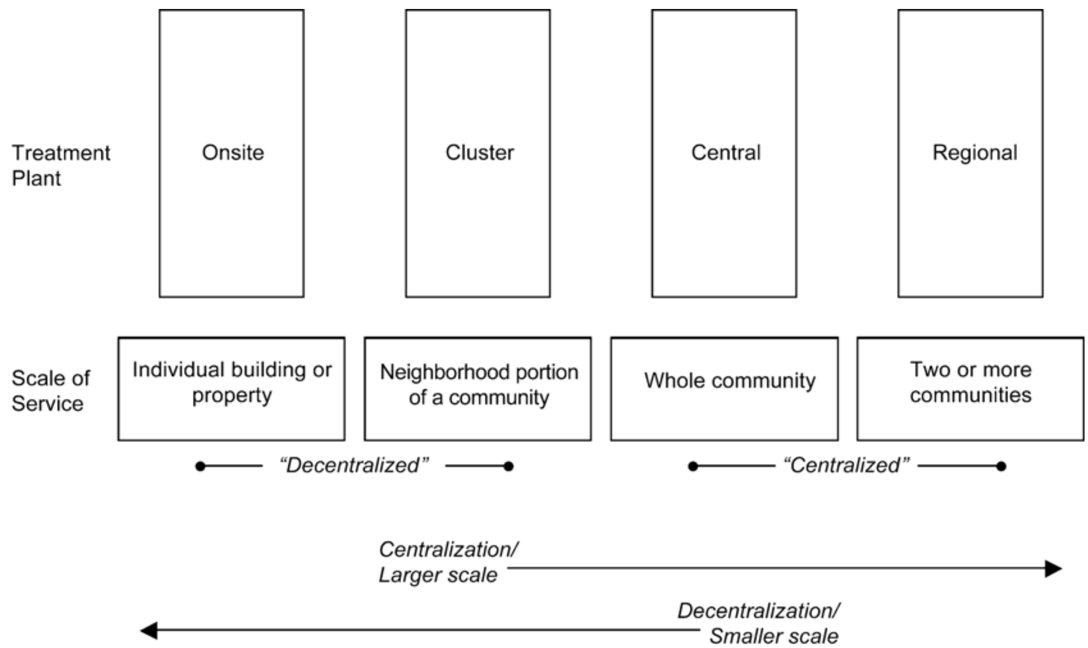

Figure 4-2: The Wastewater Scale Continuum

This report often addresses the "definition" of "decentralized" in terms of movement along the continuum. When is it appropriate to move in one direction or the other? How does moving in one direction or the other affect various system choice considerations? The focus of this report is largely on smaller communities considering options in the onsite to central system range, but it also raises many points salient to larger communities across the full range of scale, including the role of onsite systems within a largely centralized architecture, and issues regarding the relative value of multiple central treatment plants vs. one or two regional plants.

It is important to note that in this report these notions—decentralized vs. centralized, degrees of centralization, etc.—refer purely to physical characteristics, except when explicitly noted otherwise. Physical decentralization does not necessarily imply anything about institutional structures for managing wastewater systems. Maintenance of onsite systems, for instance, can be overseen by a centralized management entity such as a special district or a utility. Assuring appropriate management is a "hot topic" in the onsite and cluster field currently[3] and has been for small central treatment plants for some time. Indeed, poor management of onsite, cluster, and small treatment plants has been a driver for centralizing or regionalizing physical wastewater infrastructure for years. But, as will be discussed later, the problems often seen with decentralized and small treatment plants are not necessarily intrinsic to their physical scale, rather they may reflect inadequate technical, financial, and managerial capabilities of their owners or managers, problems that can be addressed with appropriate institutional mechanisms.

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[3] Many articles on management issues have appeared in decentralized industry journals and conference proceedings in recent years, and the EPA has developed voluntary guidelines for different levels of management appropriate to different situations (U.S. Environmental Protection Agency 2003a; U.S. Environmental Protection Agency 2003b).

5 Opportunities of decentralized wastewater systems

Following are some notable characteristics and opportunities of decentralized wastewater systems.

- *Decentralized wastewater systems can achieve high pollutant removal rates.* Most centralized wastewater treatment plants in the U.S. meet secondary treatment levels, which are generally defined as removal of greater than 85 percent of the biological oxygen demand (BOD_5) and total suspended solids (TSS). "Advanced secondary treatment" (AST) is achieved when greater than 95 percent of these constituents is removed. Research has shown that conventional onsite wastewater treatment systems with at least two feet of suitable unsaturated soil between the leachfield infiltrative surface and the water table, when properly installed and operated, can meet AST standards and provide greater than 99 percent removal of fecal coliforms. Various advanced onsite and cluster wastewater technologies can also remove substantial amounts of nitrogen (N) and phosphorus (P), some to levels approaching "advanced wastewater treatment" standards of 90 percent N and P removal (Anderson and Otis 2000).
- *Decentralized systems are often much more affordable for small communities.* For instance, in 1986 the community of Pena Blanca, New Mexico faced a cost of $3.1 million for sewers and facultative ponds, compared to $1.2 million for new septic tanks and leachfields. In 1995, Columbus, New Mexico was given estimates of $4.21 million for sewers with aerated ponds and wetlands, and $1.19 million for new septic tanks and leachfields. Willard, New Mexico in 2000 faced costs of $1.6 million for sewers and facultative ponds, compared to $0.97 million for clustered recirculating sand filters and advanced onsite systems (Rose 2004).
- *Effective management can maintain decentralized system reliability at a low cost.* For small communities, a program of once-every-three-years inspection of conventional onsite systems, plus record keeping and reporting, might cost only $30 per system per year. Programs that monitor more advanced decentralized systems on a twice-yearly basis tend to run around $100 to $150 per system per year. A robustly staffed, comprehensive program in one large unsewered community (27,000 people) costs only $25 per system per year, plus about $65 every two to twelve years for a conventional system evaluation, with the frequency depending on site conditions and previous evaluation results.[4] (See §13.1 for details and references.)
- *Decentralized systems provide another tool for large urban or suburban wastewater service providers.* For instance, the water and sewer authority for Mobile, Alabama is building and operating cluster wastewater systems to serve new subdivisions outside the city limits and on the opposite side of a topographic ridge from its gravity sewershed. The utility has found that the systems are a good match with its strategic objectives of avoiding large capital expenditures for a new treatment plant in another watershed or new force mains to serve the area, avoiding political battles over a new treatment plant, avoiding new flows in its already capacity-limited gravity sewers, providing cost-effective service to developing areas around the city, providing environmental stewardship through higher levels of treatment than septic system alternatives, generating new customers and a positive image for the utility, and using wastewater service as a tool to compete with other local water providers for lucrative water service to new development. Seattle Public Utilities is currently considering using a decentralized approach to serve an isolated pocket of the city that still uses septic systems. This approach will probably be much less expensive than extending sewers to the area.

Too few communities take advantage of these and other opportunities that decentralized wastewater systems can provide. Unfortunately, wastewater system planning is often carried out by force of habit and

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[4] Evaluation and monitoring for advanced systems is more frequent and costly.

familiarity. Communities can do better. There are many alternatives to conventional, centralized wastewater systems. And their cost-effectiveness is greater than many engineers and planners realize.

Decentralized wastewater systems are not a panacea. Proper siting, maintenance, management, and regulatory oversight is necessary to ensure their reliability—just as for centralized systems. But decentralized systems have too often been marginalized. Their costs have received more attention than their potential benefits. Only by adequately evaluating the benefits and costs of a full range of wastewater system options vis-à-vis community needs can optimal scale be determined. Facilitating such evaluations is the purpose of this report.

6 Integrated wastewater planning

A main purpose of this report is to "catalog" the broad range of potential economic benefits and costs that communities should consider when considering substantial capital investments in building, expanding, or repairing wastewater systems. Specifically, the catalog addresses many ways that the choice of wastewater system scale may result in varying benefits and costs. The intent—and another main purpose of this report—is to assist what is conventionally called "wastewater facility planning," by making it more comprehensive and representative of whole-system costs and benefits. Because wastewater facility planning as conventionally practiced is too narrow in scope, this report uses a different term, *integrated wastewater planning*, to indicate the kind of comprehensive planning and economic analysis this report assists.

A secondary purpose is to highlight techniques and tools for economic analysis that planners can use in assessing the costs and benefits of different wastewater system choices. Some of these tools are straightforward cost engineering models; others involve more esoteric concepts and techniques, such as "stated preference" surveys used in the field of environmental economics, or "option theory" from the field of financial economics. These tools are not commonly used in wastewater system planning, but they could inform the practice and help in the development of integrated wastewater plans.

Before diving into the benefits and costs that attend wastewater system scale, it is necessary to understand how wastewater systems are planned in common practice, and the shortcomings of typical practice. Community wastewater facilities planning has typically included three phases: (1) needs assessment, (2) development and screening of alternatives (particularly regarding problem areas or areas of special concern); and (3) overall, integrated evaluation of alternative plans and their area-specific sub-plans. A final recommendation, for example, would be based on a showing that the selected plan "is the most economical means of meeting the applicable water quality and public health requirements, while recognizing environmental and other non-monetary considerations (Arenovski and Shephard 1996)."

While the facilities planning process is sufficiently flexible and open-ended to include a full range of risk-reduction strategies and criteria, decentralized wastewater experts have argued that in practice the planning process has been excessively narrow in scope. Technologies more applicable to large urban systems have been carelessly recommended to small communities, while more affordable technologies such as community sand filters, pressure collection systems, cluster systems, and remedial onsite upgrades have been given little attention (Kreissl and Otis 2000). Further, inadequate consideration has been given to wastewater reuse, ground water recharge, wellhead protection, and other watershed needs and values.

The facilities planning process has also not typically addressed alternative means to reduce risks of water pollution, including stormwater remediation, repair of leaking sewer pipes, point-source upgrades, improved farming practices, and others. A proper comprehensive water quality protection plan would identify the measures which have the largest impact on reducing risks to public health and the environment at the least cost, and projects could be prioritized over time accordingly. The U.S. EPA's watershed initiatives and Total Maximum Daily Load (TMDL) agreements take this approach. EPA has also encouraged small towns to integrate risk assessment of air quality, solid waste, toxic waste, and other problems, and to proceed with high-priority, high-impact, cost-effective projects first. The improvements in efficient targeting of risk reduction funds should, however, be compared to the increased costs of planning.

Finally, the needs assessment phase of the project has typically over-simplified both the sources of pollution and the levels of pollution. Often problems such as elevated nitrogen levels in ground water or contaminated shellfish beds are attributed to septic system contamination, without investigation of sources. There are instances where sewers have been constructed and the improperly diagnosed water quality problems remain. In other instances, water quality monitoring has been insufficient to establish that serious threats to public health or the environment exist (U.S. Environmental Protection Agency 1994). Of course, the benefits from improved accuracy in determining pollution sources need to be weighed against the costs of investigation.

This report, following the lead of Anderson and Otis (2000) as well as others, suggests a change in terminology to help orient thinking in more fruitful directions. Rather than framing the wastewater system decision making process as "wastewater facilities planning," consider the process to be "integrated wastewater planning."[5] The first concept too easily turns to examination of facilities, often before consideration of larger issues. The later connotes examination of a range of wastewater issues, not just "facilities," and implies integration with other water resource issues. Further, the term "facilities" itself tends toward, for lack of a better phrase, "large things," and thereby consciously or unconsciously biases the process against small systems such as individual septic tanks, which the average person would not usually consider to be "facilities."

Taking this discussion further, note that "integrated" conveys the idea of a mix—perhaps a mix of technologies, perhaps a mix of system scale, perhaps both. So the idea is not simply centralized *versus* decentralized. Rather, integrated wastewater planning seeks fair comparison of all alternatives and selection of whatever system or mix of systems best meets the objectives of the community.

This leads us to another key point. In integrated wastewater planning, it is essential to identify desired outcomes first. Only once this is done should the planners and the community examine technologies. Put community issues and desires first, engineering second. As a corollary, it is essential that *community* planning occurs, not just wastewater planning. And community planning ideally should precede wastewater planning. Too often community "process" has been conducted solely to get buy-in to a technology. That is a recipe for disaster, as many case studies show (e.g., see the Paradise, California case study in Pinkham et al. 2004).

Fundamentally, domestic wastewater needs to be treated to reduce risks to health and the environment. However, decisions about wastewater treatment reflect additional factors, such as engineering reliability, financial costs, and political acceptability. Nelson and Shephard (1999) define accountability in wastewater treatment decisions in three major dimensions: protection of public health and the environment; community needs and preferences; and practicality or feasibility. Ultimately, integrated wastewater planning is the review and resolution of these three dimensions.

As a penultimate point, it is important to make explicit the premise of this report and of integrated wastewater planning. Communities need whole-system, lifecycle analysis to make the right decisions. This means that all costs and benefits of an alternative, inside and outside the conventional bounds of infrastructure systems, and from initial capital investments through operation and maintenance to eventual rehabilitation or replacement of an aged system, must be taken into account. Part II of this report is intended to help communities to do exactly that. It raises a plethora of considerations germane to

5 Anderson and Otis use the phrase "integrated wastewater management."

wastewater system decision making. Not all will pertain to any particular community. But any community can use this material to help see if an analysis of a proposed action has "covered all the bases."

Finally, an important aspect of garnering political support for any technological or policy decision, mentioned briefly above, is consulting the stakeholders (Sclove 1995). This can lead to development of alternatives that are better suited to the community's needs, and to greater acceptance of the chosen course of action. Involvement in the decision fosters greater endorsement of it. Integrated wastewater planners should include a robust public participation effort in their planning and decision making process.

7 Format of the benefit and cost catalog

As noted above, too often wastewater systems are planned with minimal attention to broad community issues. With only a few key parameters such as assumed population growth and development locations, too many consultants and utility managers quickly jump to design of treatment facilities and collection systems, bypassing numerous prerequisites for such a task. Integrated wastewater planning, on the other hand, puts the engineering last, after serious consideration of a range of community, watershed, aesthetic, financial, and other questions. It is the answers to these questions that should define the design problem.

Accordingly, this catalog starts with the "broadest" community issues first, and generally moves toward "narrower" issues. The first several chapters deal with community level issues: financial planning and risk, community and watershed-level impacts of wastewater system scale, and the impacts of wastewater systems on the neighborhoods and individual sites that together make up a community. Only after these discussions is the cost engineering of treatment and collection systems addressed. The next several chapters address synergies with other infrastructure, management of wastewater systems, and issues relating to reliability and failure of systems. A final chapter of the catalog discusses those aspects of wastewater system scale that have implications beyond individual communities or watersheds.

Within the chapters, issues are subdivided to various degrees, and costs and benefits of decentralized systems for each subtopic are called out. This report's typology of costs and benefits is partly calculated to introduce concepts and techniques in accessible ways. The relationships between the benefit and cost items and the lumping and splitting thereof could be constructed with other logical schemes in mind. For instance, the concepts presented in the chapter on reliability could be separated, with portions presented in the O&M chapter, in the administration and maintenance chapter, in the community and watersheds chapter, in the neighborhood and onsite impacts chapter, and so on. The catalog pulls these various issues into one chapter because "reliability" is a common and key concern of many property owners, communities, engineers, and system managers. Giving it chapter-level treatment directly addresses those concerns. Further, "reliability" is a concept with many interrelated but frequently confused aspects, such as vulnerability and resilience. Treating all these issues in one place will help the reader better understand his or her concerns on these topics.

In each chapter and chapter section, potential costs and benefits of decentralized systems—*relative to* centralized systems—are summarized by an indicator phrase in bold italics, followed by one or two sentences in italics. There are three types of cost and benefit items and corresponding indicator terms, as follows:

> ***Decentralization benefit:*** *Where smaller scale tends to produce a benefit or save on a cost relative to larger scale.*
>
> ***Decentralization cost:*** *Where smaller scale tends to produce a cost relative to larger scale, or fails to obtain a benefit available at larger scale.*
>
> ***Decentralization consideration:*** *Where there is no clear tendency for smaller scale to be beneficial or costly relative to larger scale. Rather, for this item the relative benefits and costs of different scale*

systems depend very strongly on the specific nature of the situation and the available wastewater options.

The conclusions presented by these cost and benefit items are meant to indicate “general tendencies” in the comparison of centralized and decentralized systems. Clearly there are many nuances, and under certain conditions the actual comparative advantage may be the reverse of that indicated by the summary item. The catalog tries to identify situations in which this would be the case, either within the discussion of the item, or, where the situation is more prevalent, as a separate item with the opposite “directionality” of benefit or cost. Where there is no clear direction—no clear advantage for centralized or decentralized systems—the summary item does not declare a cost or benefit, but rather, a “consideration.”

Throughout, the catalog identifies techniques and tools for economic evaluation of the benefits and costs attending wastewater systems. To avoid redundancy, generic techniques and tools useful to the evaluation of a variety of benefit or cost items are described in greater detail in Part III. Techniques and tools described in Part III are called out in the text of Part II in bold, for instance, **hedonic pricing** is an economic valuation methodology mentioned several times in Part II and described in Part III.

The benefit and cost catalog breaks down the economics of wastewater systems into many parts. However, the reader should always keep in mind the discussion above on integrated wastewater planning: taking a comprehensive view and properly assessing the sum of the parts—qualitatively if not quantitatively—is essential to good wastewater system planning. Care should be taken not to optimize components of a system while “pessimizing” the system as a whole.[6] Ultimately, what is important is the “whole-system logic” of various options, the net benefits and costs across all issues.

It is also important to note here that the relative “strength” of the evidence presented for costs and benefits varies substantially from item to item. Much is anecdotal; rigorous studies that assess the relative incidence and the degree of many of the benefits and costs noted in the catalog are lacking. This report presents anecdotes to raise awareness of possible consequences of system scale choices, and in the hopes that other researchers will follow with detailed studies.

6 “Pessimizing” refers to acting in ways that reduce the efficacy of a system, pulling away from an optimal result.

PART II – BENEFIT AND COST CATALOG

8 Financial planning and financial risk

"What will it cost?" and "How do we pay for it?" are the central questions in any practical monetary evaluation of wastewater facility choices.

The first question is typically addressed through **cost estimation** and **engineering economics**. That is, for each option under consideration, an engineering consultant evaluates capital costs such as treatment units and collection systems, estimates operating and maintenance costs, and applies a discount rate in order to make purportedly fair economic comparisons of options that have different cost streams over time. In almost all cases, this is the end of cost comparisons. The option with the lowest "net present value" (alternatively, the lowest "annualized cost") is put forward as the least-cost option. Why this evaluation is not always correct from standpoint of total economic costs, including *financing* costs, is one key topic of this chapter. Other chapters address additional costs—environmental, social, etc.—that are not typically encompassed, and rarely quantified, in engineering studies.

The second question, "How do we pay for it?" is usually treated separately from the cost question, sometimes by the engineering consultant, sometimes by local government staff, sometimes by a financial consultant. The answer to the first question is taken as a given, funding sources are identified, and wastewater rates, hook-up fees, and other revenues to support costs are determined. Ways this two-step approach can disserve a community are another key topic of this chapter.

The two questions are often highly interrelated. How one answers one question can substantially affect answers one obtains to the other. Thus, before moving on to the usual issues of capital and O&M costs, and to a host of other economic issues that flow from wastewater facility choices, larger issues in *financial planning* must first be discussed. This is essential grounding for those who make or assist decisions about what a community will spend and how it will pay for it. Concepts in this chapter may be the most novel and the most useful information in this report for communities facing weighty decisions about expanding or retrofitting wastewater systems. This chapter includes territory familiar to many in the wastewater and community planning professions—**"engineering economics"** and **"cost estimation"**—but ventures beyond into the realm of "financial economics," which concerns the economics of money itself, and the economics of the risks involved in financial decisions (Awerbuch 1993; Hoff and Herig 1997).

Financial planning generally, and the field of financial economics in particular, is an arcane subject to most people. Counterintuitive results are often encountered. This is in part because the time value of money and the opportunity costs of using money (both discussed in detail below) are easy to grasp in broad concept but hard to master in nuance.

Further, financial planning has many dimensions. A first dimension pertains to developing a comprehensive understanding of *costs.* Many different types of costs must be encompassed in a complete financial analysis:

- Capital costs for new, expanded, or improved facilities (including treatment plants, collection systems, and other assets like vehicles and computers needed to build or operate a system);
- Service of previous debts;
- Ongoing costs such as operation, maintenance, management, and administration;
- Planned replacement or renovation of assets as they age and become unserviceable;
- Accumulation of funds to cover future capital costs, e.g. replacement and renovation;

- Extraordinary expenses for unexpected damages to assets or other emergencies.

A second dimension is *revenue generation.* Communities may support costs through a variety of revenue sources:

- User charges (rates);
- Connection fees (system development charges);
- Property taxes;
- Other fees and assessments.

Financial mechanisms make up a third dimension. This is the interface between costs and revenues; that is, how communities pay at any moment in time for capital projects and ongoing costs. Options include:

- Current revenues (as noted above);
- Past revenues not yet spent (e.g. reserve funds);
- Future revenues, including those obtained through rate and fee increases, to the extent their availability matches project and ongoing costs that are to be incurred in the future;
- Debt (e.g., bonds and loans, money available now that must be repaid in the future);
- Grants;
- Donations (such as "self-help" labor and in-kind donations of time and materials from various parties to building or operating a system);
- Privatization of assets or operations, to bring to bear the financial resources of the private sector, though this type of financing still requires that supporting revenues be generated largely or entirely from the community served.

A fourth dimension concerns the *parameters of debt*. Since many infrastructure projects require a community to incur some amount of debt, factors that affect the amount and cost of borrowing must be carefully understood. The forms of debt are many, including state revolving loans, bank loans, and a host of municipal bond types (general obligation bonds, revenue bonds, limited or special obligation bonds, special assessment bonds, etc.) For any type of debt, the factors influencing its cost can include, roughly following Curley (1993):

- The term over which the debt must be repaid, which may include the construction period and other idle time before a facility is actually in service;
- The interest rate on the borrowed funds, which may be affected by a community's financial condition;
- Up-front financing costs (fees, points, costs of counsel, etc.);
- Annual carrying costs (bond insurance, etc.);
- Imposed costs, such as appraisal of properties used as collateral, title insurance, adverse re-financings, audits, etc.;
- Effects of the timing of borrowing, including inflation-adjusted impacts of chosen or imposed delays in borrowing, and more or less favorable debt terms at different points in time;
- Ineligibility in particular lending programs of certain types or amounts of costs;
- Debt service coverage ratios—the amount a lender requires that a borrower's net income (cash available for debt service) exceed debt service costs.

The interaction of these dimensions produces many implications. One is that identical projects may require quite different financial planning strategies in different communities, depending on the financial circumstances of each community. For instance, where a project may require one community to borrow funds, the same project in another community may not require borrowing, depending on differences between the communities in such factors as eligibility for grants from federal or state agencies, existing debt load from previous projects, availability of funds built up from past revenues, and ability to shift capital costs from the community to developers. Another implication is that different project configurations that appear to have equal costs in a given community, as determined by conventional cost accounting, may have different total costs once costs of financing are considered. Further, a project that appears cheaper as measured by the net present value of expected capital and O&M costs can actually have a higher *total economic* cost than a project that appears more expensive in the engineering analysis, once an eye is turned to the opportunity cost of investing in capacity that substantially exceeds current demand or takes a long time to build.

In other words, quite apart from physical and managerial economies and diseconomies of scale (addressed in later chapters) that are evaluated through the lens of engineering economics, the scale of a system can also affect its financial economics. Scale affects who bears costs, the time at which costs must be incurred, how they can be recovered, and the availability of alternative uses of scarce funds. And scale affects uncertainty and risk—and thereby the cost of financing and the cost of mistakes.

Scale has three interrelated but separable aspects relevant to financial planning: size, lead time to bring a project on-line, and flexibility in operations and upgrades:

> *Unit size*. Can capacity be bought in small increments, or only in large, “lumpy” investments? Decentralized systems are highly modular. They can be added house-by-house as growth occurs. Or cluster systems can be planned to accommodate growth with additional modules, for instance, incremental addition of sand filter beds—but the module capacity can be much smaller than the increments of capacity typically built in phased centralized treatment systems.[7]
>
> *Unit lead time*. How long does it take to plan and build each new unit of capacity? In general, lead time is correlated with size. In the case of very large centralized plants, planning, permitting, and construction can take years, in part because each plant is unique in important engineering parameters, and environmental reviews in the permitting process are lengthy. For decentralized systems, uniqueness—proper accounting for soil type, for instance—is still a feature of many of the technologies, but the engineering usually, the permitting typically, and the construction generally can be completed in short order. This will become even more the case as decentralized technologies that are less reliant on soil for treatment become more common.
>
> *Unit flexibility*. Does the size or type of unit lock one into a particular technology for future units? Because decentralized systems perform independently of each other, new technologies can be chosen at any point in the future for growth occurring from that point forward. For centralized plants, if new standards requiring new technology are put in place before the plant is near capacity, the unused capacity may become a stranded asset, or costly retrofits may be needed to make the yet-to-be-used capacity serviceable.

These aspects of scale underlie many of the financial planning concepts presented in this chapter. The discussion focuses mostly on capital costs and costs of financing for capital investments, but also addresses operating and maintenance costs and a number of other costs and financial planning opportunities.

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[7] In order to allow modularity at a centralized plant, the close-in collection system usually must be sized initially for the final build-out. Planning to upsize previously installed collection lines or add additional collection lines in already-served areas would rarely be economically prudent due to the high costs of re-disturbing collection line routes. Of course, a collection system does not have to be initially extended throughout the eventual build-out area. Thus, sewer extensions represent a certain type of “modularity.” But often the capacity along sewer extensions is not fully utilized until years after installation, once development in the area served is complete.

We turn first to some opportunities that can be encompassed within the framework of **engineering economics**. Some commonly are encompassed, others typically are not. Following sections address additional opportunities that are rarely, if ever, considered in standard engineering economics approaches to wastewater facility planning.

8.1 Capacity needs and the time value of money

8.1.1 Distribution of nominally equivalent costs

***Decentralization benefit**: By (typically) moving capacity costs to the future, the net present value of costs for decentralized systems is reduced compared to centralized systems of similar or even somewhat higher nominal costs.*

Engineers and planners recognize well the time value of money. All other things being equal, one would rather have a given amount of money now than in the future, or expend a given amount in the future rather than now. This is because a dollar earned or saved now can be invested and will provide more value in the future, and a dollar spent in the future can be "paid for" with a smaller amount of current funds that grows to the needed value in the future. To reflect this, project analysts adjust nominal costs—current and future costs estimated in constant (non-inflated) or current (inflated) dollars—by applying a discount rate. The discount rate reflects a compound yearly rate of decline in the value of money over time. Discounting future costs equalizes costs in the future with those in the present and provides a uniform basis for comparing projects with differing cost streams over time. Project revenues that offset costs, such as the value of reclaimed water sold to water systems or customers, or sales of biosolids, can be similarly discounted.

Discounting streams of costs occurring over time, depending on the particular approach used, yields either a figure for "net present value" (or "present worth") or a figure for "equivalent annual costs" (or "annualized costs"). Both methods produce analytically equivalent results, but net present value is generally preferred over equivalent annual costs in order to avoid confusion with costs that occur on an annual basis, such as operating and maintenance costs (Water Environment Federation and American Society of Civil Engineers 1998). In any case, the full lifecycle costs of all alternatives must be evaluated. These include capital costs to build a facility, future capital costs to rehabilitate or upgrade the system, and ongoing operation and maintenance costs over the project's lifetime. In addition, differences in the residual ("salvage") value of assets at the end of the project lifetime must be accounted for.

By breaking a given future capacity need into smaller units of capacity, decentralized systems allow costs for each increment of capacity to be pushed to the future, when the next increment is needed. In comparison, centralized facilities usually require larger "lumps" of investment up-front, based on a projection that a certain amount of service-area growth will occur and demand will "grow into" the excess capacity over time.

Discounting future-loaded cost streams results in lower net present value, and thus lower costs, compared to a front-loaded cost stream of similar nominal cost. Moreover, a nominally more expensive future-loaded cost stream can also be cheaper. In such conditions, all else being equal, decentralized systems are a "better buy." Such a result can occur in areas where the density of development being served is around the "breakeven point" between the advantages of centralized systems in gaining economies of scale in treatment systems and the advantages of decentralized systems in avoiding diseconomies of scale in collection systems, and would be discovered in any competent engineering analysis of different options for wastewater system architecture for a community thus situated. These tradeoffs in scale economies, and the related issue of managerial economies of scale, are considered in later chapters.

Moving costs to the future may be unwise if cost escalation for the anticipated systems is expected to exceed the discount rate. Capital, O&M, and managerial costs should all be considered. Estimating relative rates of cost escalation between centralized and decentralized systems is rather speculative, but given that capital costs for decentralized systems are expected to decrease as technologies become more standardized and mass produced, and that managerial costs will probably decrease as administrative systems improve and technologies for remote monitoring allow reduced staffing, decentralized systems may enjoy lower cost escalation than centralized systems.

Standard **engineering economics** techniques adequately encompass valuation of differing costs streams over time, and thereby provide a straightforward method for valuing the more incremental distribution of costs allowed by use of decentralized systems. Standard engineering economics texts (e.g. Sullivan et al. 2003) provide the equations and discuss in detail how such analyses are performed; wastewater planning manuals encourage their application (Water Environment Federation and American Society of Civil Engineers 1998); much engineering software facilitates their calculation; and most any engineering or planning firm is competent in the basic techniques.

8.1.2 Deferral of conventional capacity

Decentralization benefit: *Decentralized systems can reduce the net present value of wastewater system costs by deferring or downsizing the need for replacement systems.*

In many cases it may be economically prudent to use decentralized technologies to delay implementation of centralized systems, even if the decentralized technologies have higher costs per unit of capacity or per capita and/or will be replaced by the centralized system. If the centralized capacity expenditure is sufficiently large and can be delayed sufficiently long, the present value of deferring the investment may be larger than the smaller near-term expenditures on “more expensive” decentralized capacity. Of course, if delaying a centralized capacity expansion would significantly increase its costs—for instance, by requiring more expensive sewer line trenching due to disruption or avoidance of other infrastructure installed in the interim—deferral may not be prudent. Evaluations of deferral value must be carefully made on a case-by-case basis.

In Alabama, the Mobile Area Water and Sewer Service utility (MAWSS) has recently elected not to extend sewer lines to a large, rapidly growing area located outside of the main watershed it serves. Instead, MAWSS is participating with developers in the costs of building cluster systems to serve growth outside its sewer collection area, assuming management of the facilities, and charging hooked-up residences and businesses as if they were sewer customers (albeit at a higher rate currently, as MAWSS does not yet have a confident estimate of the actual O&M and management costs). In the future, the utility may sewer the area by connecting the clusters, or it may leave the area on cluster treatment. It will not have to make this decision for many years (Pinkham et al. 2004).

Centralized facilities can also be deferred by upgrading selected onsite systems. Frequently, a few failing septic systems in a town or subdivision may spark a wastewater facility planning process. Often the options analyzed are “all or nothing”—extend sewers to the subdivision, install a cluster system for the entire subdivision, or install new/improved onsite systems throughout. Incremental replacement of only the failing systems should be considered. That is, replace or upgrade currently failing systems now, and others 5, 10, or more years down the road as they fail. This can spread costs substantially, resulting in much lower present value costs.

While use of decentralized treatment systems to defer major capacity expansions may seem novel, it should not. The ultimate decentralized approach is water end-use efficiency, or “water conservation.” Using high-efficiency fixtures, appliances, commercial water use processes, and the like is now a widely recommended and widely used practice in both the water and wastewater industries in part because it allows utilities to defer capacity expansions.[8]

8.1.3 Service life extension of existing infrastructure

Decentralization benefit: *Decentralized systems can help extend the useful service life of existing conventional infrastructure.*

Decentralized systems can potentially reduce the load (continuous and/or peak) on conventional facilities in ways that could extend their useful lives. This then pushes replacement project costs into the future, cutting their cost in net present value terms. For instance, Etnier et al. (2001) describe two such opportunities:

> In certain circumstances, it may make economic sense to hook up the blackwater from sewered houses to a decentralized system. Where sewers are in need of renovation but the sewers are hard to find, it may be possible to treat the blackwater separately and use the sewers for graywater. There have been discussions in the town of Ås, Norway, about doing just that. With solids content of the blackwater removed, the thought runs, the existing sewer pipes may not have clogging problems and their useful lifetime may be extended significantly. This could also be a model for a two-stage decoupling of a centralized system. It is quite conceivable, when the present sewer line becomes unfit for even graywater, that it would be less expensive to install onsite systems for graywater treatment than to install new sewers for just the graywater.
>
> A nearby dormitory for students at the Agricultural University of Norway was recently built using vacuum toilets to collect the blackwater in a holding tank, from which it could be hauled for treatment in a specially developed reactor and land application. The vacuum pump that this system uses is capable of handling hundreds of toilets, and transporting the waste hundreds of meters. Since the vacuum pipe is both much smaller than a sanitary sewer pipe and does not have to be buried as deep, there has been discussion of renovating the sanitation system by building a vacuum-based cluster collection for the blackwater, with the graywater still going to the existing sewer pipes.

The value of this benefit is determined in the same manner as determining the value of new project deferral. Standard **engineering economics** approaches are appropriate.

8.1.4 Opportunity costs of idle capacity

Decentralization benefit: *The small unit size of decentralized systems allows closer matching of growing demand for wastewater capacity; therefore, less money is tied up in overbuilt capacity.*

Decentralization benefit: *Decentralized systems can shorten project lead time—e.g. the construction period—further reducing the cost of tying up funds unproductively.*

Decentralization benefit: *In cases when future demand fails to meet expectations, additional scheduled increments of decentralized capacity can be foregone, avoiding the cost of overbuilt centralized capacity.*

Decentralization consideration: *Because cluster systems tie-up more time and money in permitting and implementation than do conventional onsite systems, developers may favor onsite systems and the potential benefits of cluster systems may be foregone.*

Centralized capacity additions inherently overshoot demand (absent gross under-forecasting or exactly predictable step-function increments of demand) because their inherent "lumpiness" leaves substantial increments of capacity idle until demand can "grow into it." In contrast, smaller units can more exactly match gradual changes in demand without building unnecessary slack capacity—they provide "build-as-

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[8] Water efficiency is recognized as a way to extend the life of facilities or defer capacity or treatment upgrades across the full range of wastewater facility scale. For instance, installing water-conserving fixtures and appliances is considered a viable approach to a variety of home septic system problems (Rubin 1982; Sharpe et al. 1984).

you-need" or "just in time" capacity—so their capacity additions are employed incrementally and immediately, as shown in Figure 8-1.

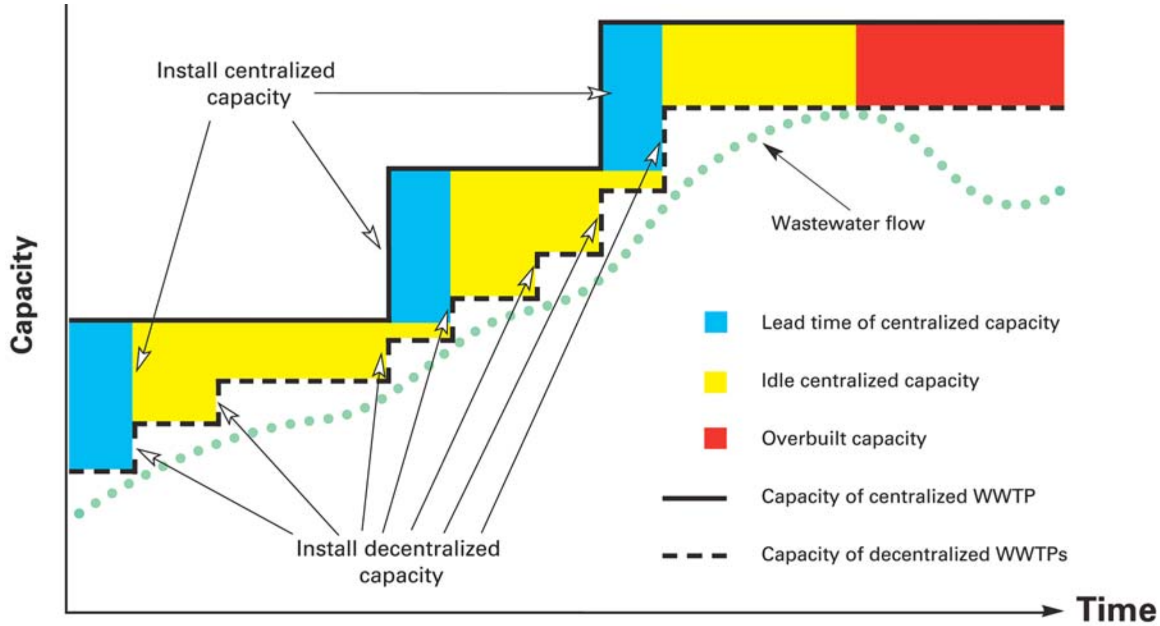

Figure 8-1: Flow Versus Capacity for Centralized and Decentralized Wastewater Systems. WWTP stands for Wastewater Treatment Plant.

Figure 8-1 shows that smaller, faster-to-build modules of capacity save three different kinds of costs: the costs of the increased lead time of slower-to-build central resources;[9] the cost of idle capacity that exceeds current need for sometimes significant periods of time; and the costs of overbuilt capacity that remains idle. Both the lumpy and the incremental capacity "curves" maintain sufficient capacity to serve the erratically growing demand curve, but the small-module strategy does so more exactly in both quantity and timing, and hence incurs far lower cost.

This load-tracking ability has value unless demand growth not only is known in advance with complete certainty, but also occurs in step-functions exactly matching large capacity increments. If that is not the case—if the growth graph is diagonal rather than in vertical steps, even if it is completely smooth—then smaller, more modular capacity will tie up less idle capital for a shorter period.

How do these differences in capacity translate to cost? The key economic concept here is "opportunity cost," which economists define as the highest-valued alternative use of a resource. The resource in this case is the funds invested in building wastewater capacity. Alternative uses of those funds are of course myriad. Rather than attempting the analytical gyrations of placing a value on putting the funds into roads or schools or other uses, a practical valuation technique is to apply the discount rate to determine the net

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[9] The lead time of concern here is the construction period for a treatment unit, or more generally, the time during which borrowed money is not delivering value (treatment). In some cases, the time necessary for planning a decentralized system may be greater than the time required to plan a centralized one, due to increased needs assessment and public participation efforts. However, typically little money is tied up in this stage. Money mostly tied up in the construction phase. While the overall construction phase can last longer—sometimes much longer—for many decentralized facilities compared to a single centralized one, the unproductive wait time for each decentralized unit (which is typically financed on an individual, as-needed basis rather than within a larger public financing scheme) is much less than for a single centralized treatment facility.

present value of funds that are tied up in a larger, slower-to-build project—funds that could be freed up by instead building smaller, faster units of capacity. In effect, this approach tells us the value of the lost opportunity to invest funds at the discount rate instead of tying them up unproductively in construction and unnecessary capacity.

Note that the concept of opportunity cost applies whether or not a community borrows money to finance a wastewater project. Value is foregone whenever funds are spent unnecessarily because capacity is built too soon, whether the funds are borrowed or not.

If demand grows steadily, the value of avoiding lumps of temporarily unused capacity can be estimated by a simplified method modified by Hoff, Wenger, and Farmer (1996) from a 1989 proposal by Ren Orans. The extra value of full capacity utilization is proportional to:

$$\frac{(d - e)T}{1 - exp^{-(d - e)T}}$$

where *d* is the real discount rate, *e* is the real rate at which capacity cost escalates, and T is the years between investments (capacity of the investment divided by load growth). In any actual planning situation, depending on the fluctuating pattern of demand growth, the extra cost of carrying the lumpy idle capacity can be calculated from the detailed assumptions, and then interpreted as a financial risk (see §8.2).

This approach also provides a closed-form analytic solution for the case where the decentralized resource is becoming cheaper with time, so even if it's not cost-effective now, it is expected to become so shortly. If the relative rates of cost change between the distributed and traditional resources are known, due allowance can be made. The equations provided in Wenger et al. (*Ibid.*) can also use **option theory** (§18) to account for uncertainties in the cost of the decentralized resource. As might be expected, such uncertainty may create additional advantage by suitably structuring the option so that the utility is positioned but not obliged to buy, depending on price.

The real economic cost of idle capacity, though not encompassed within ordinary cost accounting, means that the construction costs of large, long-lead time plants must be considerably less on a per unit basis than small, short-lead time plants for larger plants to be the economically prudent choice. For instance, Swisher (2002) provides an electric power industry illustration of the value of small, quickly implemented distributed power generating units compared to conventional centralized power plants. The equations used and the numerical results would be the same for a wastewater industry case under the same assumptions. Assume decentralized systems can be built in exactly the increments needed to meet annual capacity demand growth, with a one-year lead time, while centralized systems take longer to build and must be larger in capacity than a single year's growth in demand. On those assumptions, Table 8-1 shows the percentage increase in the net-present-value cost of the central facility compared with distributed facilities *with the same unit capital cost*. For example, if the centralized system has a capacity increment equivalent to six times the annual load growth, and a two-year lead time, it carries an effective 32 percent cost premium compared with a decentralized system with the same cost per gallon of capacity. Conversely, in this situation the decentralized system could cost 32 percent more per gallon of capacity and still yield the same net-present-value capital charge as the centralized system. The only difference is in their lead-time and their "lumpiness": the centralized system costs more because it must be built earlier and because it has excess capacity until demand catches up.

Table 8-1: Net Present Value Benefit of a Small Resource with a 1-Year Lead Time

Size Ratio	Large Resource Lead-Time (years)				
	1	2	3	4	5
1	0%	5%	10%	16%	22%
2	5%	10%	16%	22%	28%
3	10%	15%	21%	27%	34%
4	15%	20%	27%	33%	40%
5	20%	26%	32%	39%	46%
6	15%	32%	38%	45%	53%
7	31%	37%	44%	52%	60%
8	36%	43%	50%	58%	66%
9	42%	49%	57%	65%	73%
10	48%	55%	63%	72%	81%

The figures show the cost advantage of a small system with a 1-year lead time compared to a resource of equal unit cost, but with a longer lead time and larger capacity. The size ratio is the capacity as a multiple of annual growth in capacity demanded.

Source: Swisher (2002), Table 2.

To our knowledge the values of decentralized systems illustrated above—avoiding investments in idle capacity, and shortening economically unproductive lead time—have not been quantitatively analyzed in any wastewater facility plans. However, these values have been qualitatively addressed in some plans. For instance, in 1998 four growing communities around Olympia, Washington chose to serve projected population growth of 43,000 people through 2020 by building a series of small (0.5 to 3.0 million gallons per day, or MGD), distributed treatment facilities over the period, instead of building one much larger treatment plant now and a single expansion to that plant later in the planning period. Among the many benefits of this "Highly Managed Alternative" (referring to the need and opportunity for on ongoing planning process to continually assess sub-area demand requirements and other changing conditions), the facility plan that recommended this scheme noted:

> The Highly Managed Alternative relies on small increments of new capacity being added 0.5 to 3.0 MGD at a time. These increments will be added in a tightly managed manner to match as closely as practical actual needs for added treatment and conveyance. Adding capacity in small increments also provides the opportunity to take advantage of improving technologies and reduces the risk of over-commitment to any single technical approach. …
>
> By shortening the time between identification of a capacity need and implementation, The Highly Managed Alternative allows for rapid adjustment to changing rates of growth and tailoring of capacity increments to actual needs. It also postpones capital investment until actually needed. This concept can be described as "just-in-time" capacity (Brown and Caldwell and Associated Firms 1998).

The importance of project lead time and the opportunity costs of idle capacity can also be seen in decisions by developers who choose onsite systems instead of a cluster system to serve a subdivision. While a cluster system may ultimately have lower costs for subdivision residents and may provide better treatment than septic systems, they typically take longer to design and permit. This extra time has a real cost to developers, who typically need to begin selling houses as soon as possible to pay back lenders and re-coup an investment. Further, because a cluster system will serve a large number of lots, some of which may not sell for a long period, the developer must front the money for each lot's capacity requirement until the lot is sold. In contrast, with onsite systems a developer fronts no money, as the cost of an onsite system is shifted to the builder or homeowner who buys the lot. Or if the developer is also the builder, he fronts smaller amounts of money at any one time, as each home's onsite system is built. These dynamics, which may push a developer towards onsite systems in situations where a cluster system would be better from a community perspective, should be kept in mind by local officials as they consider wastewater codes and make plans for desired types of wastewater service. Allowing cluster systems does not guarantee that developers will build them, in spite of advantages to the public or even to the developer.[10]

8.2 Financial risk and option value

Decentralization benefit: *The flexibility of decentralized resources allows managers to adjust capital investments continuously and incrementally, more exactly tracking the unfolding future, with continuously available options for modification or exit to avoid trapped equity.*

Decentralization benefit: *Modular, short-lead-time technologies valuably temporize: they buy time, in a self-reinforcing fashion, to develop and deploy better technologies, learn more, avoid premature decisions, and make better decisions. The faster the technological and institutional change, the greater the turbulence, and the more uncertain are future needs, the more valuable this time-buying ability becomes.*

The goal of physical capacity planning is to provide a needed service at an affordable cost. Successful capacity planning might also be defined as planning that minimizes future regret—regret that one built too much, or too little, or the wrong kind of capacity. The more closely planners can approach the ideal of "build-as-you-need, pay-as-you-go," the lower the potential regret, and the lower the economic risk.

Flexibility in adjusting to future conditions is central to minimization of regret. In a planning and management context, "flexibility"

> ...is generally used to describe the ability to do something other than that which was originally intended....Similar terms...are 'adaptable' and 'versatile' (defined respectively by the *Concise Oxford Dictionary* as 'capable of modification' and 'able to turn readily from one activity to another').
>
> Other things being equal, one position is more flexible than another if:
>
> (1) It leaves available a larger set of future positions. ...
>
> (2) It allows the attainment of new positions in a shorter period of time. ...
>
> (3) It requires less additional cost to move to another position.
>
> (Chapman and Ward 1996, references omitted)

There are many potential tradeoffs between these dimensions. Obviously, flexibility is not desirable *per se*, but only insofar as its benefits exceed its costs. That is, "Flexibility is valuable in so far as it is able to reduce the cost of inflexibility" (*Ibid.*, p. 35). Until recently, however, flexibility's benefits were qualitative and abstract while its costs seemed quantitative and concrete, so big investment decisions tended to default to the inflexible but measurable. Now new tools from financial economics are starting to shift that balance, encouraging the purchasing of flexibility where it is worthwhile. This may result in preferred decisions that appear to traditional utility planners to be counterintuitive, such as deliberately building *less* conventional capacity than required to meet expected demand; but that is the right answer if flexible resources create an asymmetry in the over/undercapacity "penalty function" (*Ibid.*). Traditionally, engineers are loath to risk under-building. But decentralized resources allow "catching up," if needed, at a

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[10] Cluster systems can provide a developer more freedom in laying out a subdivision, can increase the marketability of lots to home buyers who do not understand or wish to live with a septic system, and can provide other development advantages. See the Lake Elmo case study in Pinkham et al. (2004).

price premium that may be less than the cost of carrying the capacity "cushion" that lumpy centralized investments hold for years, as seen in the previous section.

To that discussion of idle capacity, this section now adds the element of risk—the risk of choosing the wrong amount of capacity, or the wrong type, or of other events and developments imposing unplanned-for costs.

Readers will quickly recognize that because many decentralized technologies are not yet well-developed or generally well-managed, they involve a higher degree of risk than centralized technologies. This section of this report draws attention to far less-recognized ways in which the scale of systems, rather than the type of technology itself, affects risk. These factors tend to tilt in favor of decentralized systems.

The theoretical future envisaged in traditional infrastructure planning is deterministic, making most economic risk issues seem invisible and therefore unnecessary to consider. Cost estimates are prepared and systems are chosen based on the planners' best predictions and judgments about future needs. But the *actual* future inhabited by wastewater service providers and users is not deterministic at all. Rather, it *gradually unfolds* in unpredictable ways. The inevitability of uncertainty in how that future unfolds makes modular resources especially valuable. Why? Because, as financial-economics consultant Dr. Shimon Awerbuch (1996, pp. 25-26) correctly notes, modular resources create

> ...valuable *flexibility* options since managers can install capacity slowly, over time, to match load increases. Moreover, capacity expansion decisions become more routine—like the installation of additional telephone central office capacity—and hence less costly. Recent work on flexibility suggests that when valued in a traditional manner, inflexible projects are comparable to [*i.e.*, potentially competitive with] flexible ones only if their present value is considerably greater.

Consider, for instance, the importance of choosing the right investments by understanding the dynamic nature of the demand-growth process. Hoff and Herig (1997) have shown that on reasonable assumptions for an electric power industry case, the cost premium worth paying for a modular resource can easily double using a dynamic rather than a static model of demand—for reasons similar to those described in §8.1.4.[11]

From a slightly different perspective (Morris 1996), deferring major resource commitments has a direct economic value (saved carrying charges and opportunity costs), and that deferral can be achieved by

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[11] This chapter draws heavily on rapidly developing experience and theory in the electric utility industry, as summarized in a recent report by Rocky Mountain Institute, *Small Is Profitable: The Hidden Economic Benefits of Making Electrical Resources the Right Size* (Lovins et al. 2002). Electric utilities, for financial and other reasons, increasingly are turning away from large generating units and towards "distributed resources"—small-scale systems such as combined cycle gas turbines, wind power, photovoltaics, and other technologies. While the theory of financial planning for infrastructure capacity is essentially the same across utilities, some of the advanced risk adjustment concepts that have gained currency in the energy industry have not yet been applied in the water and wastewater fields. This is at least in part because the water and wastewater industries experience a very different timescale of perceiving and experiencing planning issues than the electric industry, and a widely varied set of problems that may affect how concepts for analyzing electric distributed resources can be applied. A prominent energy industry analyst, Paul Chernick, notes that electric utilities face a fairly standard set of problems (load growth, fuel price changes, etc.) *across the industry* and *on a fairly continuous basis (Chernick 2001)*. Water and wastewater utilities, on the other hand, typically have very infrequent capacity planning problems (on a time scale of every five to 20 years) and face very varied and place-specific issues (a contamination problem here, gradual approach to capacity limits there, sudden loss of capacity due to environmental rulings, sudden loss of access to another community's facility, and so on). There has also been more pressure to apply risk adjustment concepts in the energy industry because the financial stakes are often greater and more keenly felt—most electric utilities are investor-owned, while most water and wastewater systems are publicly-owned, which provides opportunities (often problematic ones) for diffusing costs and the consequences of mistakes. Nonetheless, we present these concepts here because of their potentially high value for wastewater facility planning.

substituting small investments which, while not allowing an option to revisit the big investment decision later, meanwhile allow more learning before deciding. Smaller, faster modules can therefore allow an intelligent response to the uncertain-load dilemma that Applied Decision Analysis consultant Peter Morris draws as shown in Figure 8-2.

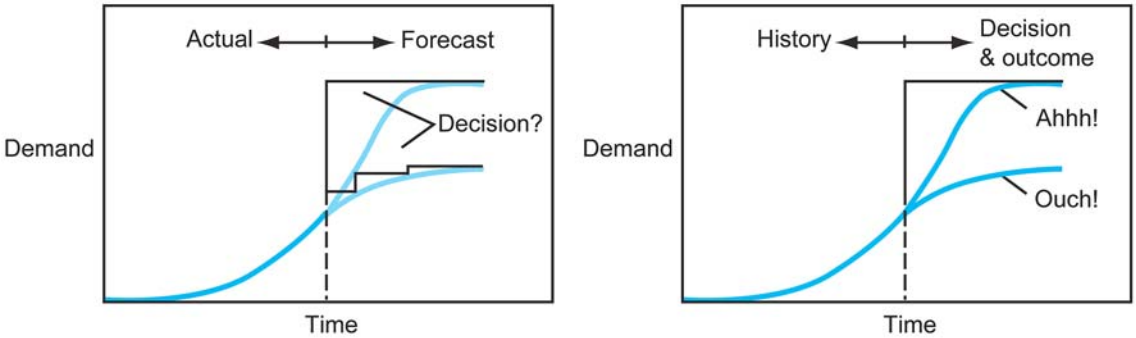

Figure 8-2: Forecasting Risk and Outcome – Small Modules Minimize Regret. *Source: Adapted from Morris (1996).*

Regret can come from many directions. Risks inherent in predicting or estimating future conditions are varied:

- *Forecasting risk*—getting a demand forecast wrong, as shown in Figure 8-2 above;
- *Planning risk*—having a plan that took much effort and cost to develop rejected by permitting agencies, voters, or courts;
- *Delayed implementation risk*—delays in construction, permitting, etc. that add cost;
- *Operational cost risk*—escalation of operating costs beyond the levels planned for;
- *Risk of technological obsolescence*—choosing a technology that turns out to be sub-optimal as other technologies become available;
- *Risk of regulatory obsolescence*—building a system that is inadequate to meet unexpected changes in regulatory standards.

What tools can measure how well different decisions can maximize the “ahhh-to-ouch” ratio? As described in the valuation tools section, **option theory** (§18)—widely used in sophisticated management of financial instruments such as stocks and bonds, and increasingly applied to evaluation of real assets such as infrastructure—is one way to put an economic value on the way modular resources create managerial options that, if exercised *in the future*, are beneficial even though they do not affect short-term accounting costs (except in paying for the option itself). That is, rather than comparing the net present values of decisions envisaged *now*, option theory assesses the additional value of flexible *choices* now to delay a decision until more is known.

Option theory helps to recognize and value opportunities where “the range of potential outcomes presents an upside potential that can be quite high. The downside risk is only the cost of procuring the option, which is much more limited than the possible loss resulting from a sunk investment in an uncompetitive resource.” Capturing that spread yields “a ‘just in time’ resource commitment philosophy” in which “shorter lead time resources possess value beyond what is indicated by a standard [net present value] calculation because they allow a utility to wait for better information and thereby eliminate some uncertainty prior to commitment.” (Kaslow and Pindyck 1994).

The basic concepts behind valuation of options are expected value and willingness to pay for protection against expected value not being obtained. The planner essentially asks, “what value (cost) of making a mistake would be intolerable?" Then s/he asks, "what am I willing to pay to be protected against that risk?" For instance, let's say the intolerable risk is overbuilding capacity by $1 million. If growth to support that amount of capacity does not materialize, the impacts on the financial condition of the utility would be severe, and rates would have to rise to politically infeasible levels. How much might one pay to avoid that risk (effectively, to be insured against it)? Not $1 million. Probably not $500,000. Maybe $100,000? The result is the amount you should be willing to pay above and beyond the cost of the original project for an alternative that provides protection against that risk. In this case, such an alternative might be a decentralized capacity plan that allows one to "stop short" if demand does not materialize, thereby avoiding a $1 million loss, or to pay $100,000 more than the centralized plan to build-out decentralized units to supply needed capacity if growth does occur as assumed.

Another important approach to valuing flexibility and modularity uses **decision analysis**—a quantitative technique rooted in operations research, management theory, and financial economics (§18.2). If you know what choices you will have at a series of future times, what you will *then* know (and with what certainty) to help make those choices, and how much each outcome is worth, then decision analysis uses an elaborate simulation of millions of possible decision trees to determine the optimal decision under each set of possible conditions, and thence the optimal decision policy to pursue under the assumed uncertainties.

This theoretical framework tends to be more deterministic than the decision maker's real world, which is full of all kinds of wild cards, including changes in the structure of the whole problem. It also requires specific assumptions to be made about the value and probability of future choices—a requirement that may not be a great deal easier to satisfy than knowing the future itself. However, decision analysis does differ fundamentally from, and can yield better decisions than, the traditional engineering-oriented methods of dealing with uncertainties: namely, to

- ignore them, or
- recognize a number of possible outcomes and assign judgmental probabilities to them, but still pursue a single probability-weighted course of action[12], or
- recognize them and develop a different course of action depending on how each key uncertainty unfolds.

Decentralized wastewater systems provide alternatives to the engineering profession's traditional tendency to approach uncertainty and risk by overbuilding. A usual engineering objective has been to minimize certain real or perceived downside risks of building too small—for instance, lost economies of scale, or new rounds of engineering and permitting. Given engineers' responsibilities for infrastructure adequacy, public health, and environmental protection, this orientation is understandable. But this approach has ignored other downside risks of large capital investments, such as those mentioned briefly above, and detailed below, as potential sources of "regret." This approach further ignores that the relative cost of "overage" – building too much capacity – might significantly outweigh the relative cost of "underage" – not building enough. Given the huge current gap between water and wastewater infrastructure needs and actual spending (U.S. Environmental Protection Agency 2002b), overbuilding either the size or the type (e.g. treatment level) of systems is no longer financially tenable or professionally responsible. Its costs will be increasingly questioned as the availability and value of alternatives that provide quantitative and qualitative security with less capital risk become more widely recognized.

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[12] This approach is still being adapted by some analysts to distributed utility planning, for instance in the electric power industry (Morris 1996), but seems attractive more for its similarity to familiar planning tools for centralized systems than for its recognition of the unfolding-future context of making decisions to minimize regret.

We turn now to examination of different types of financial risk and how decentralized systems can provide valuable flexibility to reduce them.

8.2.1 Forecasting risk

Decentralization benefit: *Smaller, quick-to-build units of decentralized wastewater capacity offer flexible options to planners seeking to minimize regret, because capacity can be added or foregone to match actual demand.*

Decentralization benefit: *Shorter lead-time and smaller size reduce the planning horizon, consequently decreasing the amplification of errors in forecasting demand with the passage of time.*

Section 8.1.4 on the opportunity costs of idle capacity introduced the notion that incrementally adding smaller units allows closer matching of capacity and demand curves. That section's discussion of the opportunity cost of choosing systems that carry extra capacity or tie-up money in a longer construction period addressed the value of decentralized systems from a deterministic viewpoint of highly predictable demand. This section considers the value of risk-reduction in cases of uncertain demand.[13]

The costs of getting demand projections wrong occur in both time and space. In time, in the sense that demand may take longer (or shorter) to reach built capacity than predicted, thus stretching out the period in which a community must pay the opportunity costs of tying up funds. And in space, in the sense that planned-for physical space—capacity—might never be needed, or might be too little. In addition to the opportunity costs of these errors, the financial impacts on a utility and its ratepayers—at least in the case of too much capacity—can be substantial and devastating. To the extent central plants or sewer systems are built with excess capacity for growth, they produce trapped equity if growth does not materialize. Community affordability for such systems is often predicated on future growth buying-in with hook-up fees and providing new ratepayers, so the costs of slower-than-expected growth, and the costs of over-estimating terminal demand, can be severe. Strategies that reduce the risk of incurring these costs have a value that reduces their costs relative to riskier strategies.

Planners can err in their demand predictions in a number of ways:

- population projections may be incorrect;
- assumptions about per capita wastewater production may turn out to be inaccurate as changes occur in both the types of uses contributing wastewater to the system change and the water efficiency of those uses;
- key businesses, industries, or other large users of the system may go out of business or reduce their needs (perhaps by developing their own treatment systems), or increase their needs. New large users may come to town.

The longer the time lag in planning and building capacity, and the larger the increments of capacity built, the farther into the future a demand forecast must be made, and therefore the greater the uncertainty inherent in the above factors and other assumptions underlying a capacity forecast. This is no simple matter. Over the very prolonged timescale—traditionally one to several decades—for the capacity of centralized plants for growing towns and cities to become fully utilized, demand forecasting becomes more like what the military calls a SWAG ("scientific wild-assed guess").[14]

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[13] A somewhat related but conceptually separable issue in matching capacity to demand occurs at the onsite and cluster system scale due to minimum design flow requirements in wastewater codes. These requirements may result in underloading of small systems, which affects their ability to function properly. See §11.1.1.

[14] Given this chapter's use of concepts and examples from the electric power industry, it is interesting to note differences between the structure of forecasting risk between it and the wastewater industry. The key difference is that power planners build into an electric power grid of statewide and interstate scale, while wastewater

As an example of forecasting risk, a recent analysis by Rick Giardina and Associates for a National Decentralized Water Resources Capacity Development Project study (Pinkham et al. 2004), compared total capital, O&M, management, and financing costs for centralized and onsite alternatives in a hypothetical community, "Smallside, USA." This rural community was imagined to grow from 500 to 1,600 homes (1,270 to 4,064 people) over a 30-year period. The assumed housing density and environmental conditions in the community were carefully chosen so that the likely centralized and decentralized (onsite) system alternatives had the same net present value for capital, O&M, and management costs. In other words, a conventional engineering analysis would conclude that there was no economic difference between the alternatives. Structuring the case study this way allowed the analysis to focus on differences in financing costs.

The analysis included a sensitivity case in which less growth occurs than had originally been anticipated when the community made its wastewater system decision. (See also §8.5 on amount and period of debt and §8.2.4 on operational cost risk for additional findings from this study.) The low growth scenario is depicted in Figure 8-3, which compares the original growth projection to the "actual" growth experienced in this sensitivity case. Lower-than-expected growth results in a longer period of underutilization of the centralized system or construction of fewer onsite systems than originally planned.

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planners build for the markedly smaller scale of individual developments, towns, or sometimes metropolitan areas. The "fortunes" of wastewater systems, thus, are captive to the particular fate of small areas and sometimes of large users within that area, and do not benefit from the risk-reducing effect of averaging of demand across large numbers of users that the electric power system enjoys. On the other hand, electric utility planners face the fact that *other* utilities (let alone non-utility producers) are simultaneously making similar, but not necessarily coordinated, forecasts and investments to supply the same interconnected grid. This does not protect against each utility's own forecasting errors, and may make them worse by reinforcing a "herd instinct." Further, demand across the grid is much larger than any particular power plant, so small percentage errors in forecasting future demand may in the long-run timeframe of planning and building large power plants amount to the size of the plant itself, and if its power is uncompetitive in price, it may become an entirely stranded asset. Wastewater planners are much less likely to see an entire large facility be unneeded or its capacity only marginally used. Nonetheless, the financial impact of forecasting errors can be equally or more devastating, given the small rate-base of so many wastewater utilities.

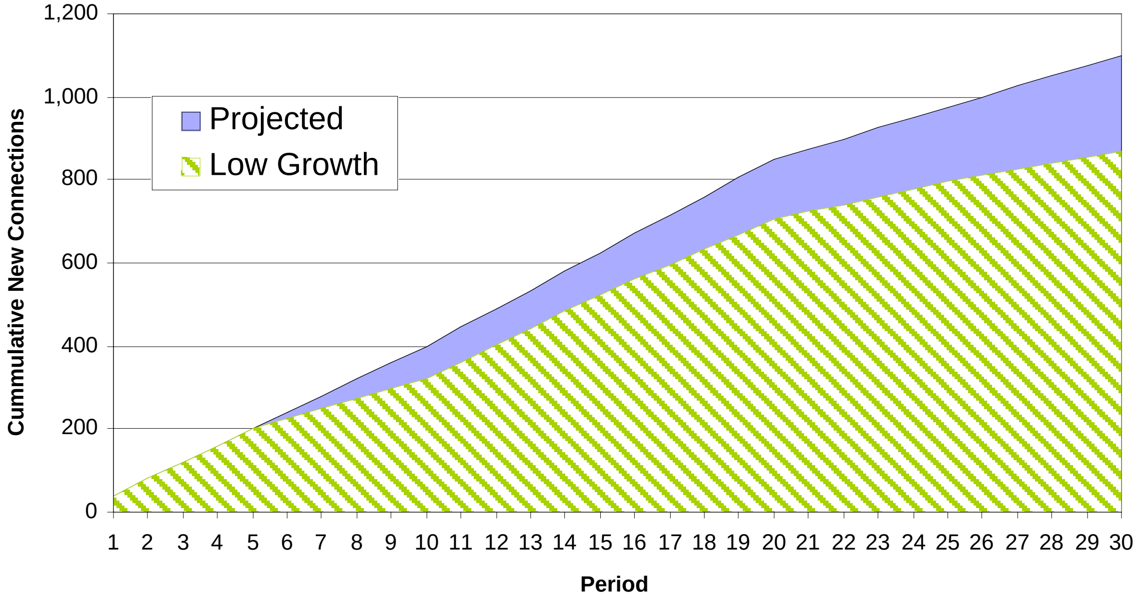

Figure 8-3: Projected Versus Low Growth for "Smallside, USA." *Source: Pinkham et al. (2004), Figure 4-4.*

Under this case, the assumptions about how the centralized system expansion plans are modified by the township as the lower-than-expected growth is realized are important to the financial outcome for the centralized scenario. More specifically, as the township grows, the centralized system—especially its sewers but periodically its treatment plant capacity as well—would typically be expanded in anticipation of serving each neighborhood. The *initial* treatment plant and collection system capacity is the same in both the base case and low growth scenario. In the low growth scenario, it is assumed that some learning occurs as slower growth is observed. Therefore, the out-year expansion of the treatment plant is delayed and downsized, and collection system expansions are also somewhat delayed and downsized compared to the base case scenario. In spite of these adjustments, some underutilization of the system's capacity still occurs. For instance, it takes longer for the initial treatment plant and sewer capacity to be fully utilized. The underutilization results in higher average annual costs for the smaller number of residents who must meet the debt obligations of a centralized system that has excess capacity. The increase in the average annual payments in this particular example is about 12 percent. Under the onsite system scenario, average annual payments change somewhat,[15] but generally are at the same level as in the base growth case. Because fewer homes are built, less onsite system capacity is constructed. The average payments increase 4 or 5 percent over the base case, depending on whether the onsite systems are owned by the town or by the homeowner. The difference in increased annual payments of 7 or 8 percent between the onsite and centralized reflects the increased risks of financing a centralized system compared to an onsite approach.

[15] Payments change due to changes in the mix of onsite technologies across sub-areas of Smallside, based on the study assumptions about the level of onsite treatment needed in certain sub-areas and the relative rates of growth in the different sub-areas.

8.2.2 Planning risk

Decentralization benefit: *Because decentralized systems often cost less to plan and design than centralized systems, they generate less exposure to lost costs if a plan is turned down by voters or regulators.*

Any planning effort runs the risk of its results being rejected, and its sunk planning and design costs becoming an unfortunate waste. A community could spend much effort and money planning a new wastewater facility and then have that plan rejected by regulators or by voters in an initiative ballot or bond referendum. Decentralized systems may face fewer and less costly hurdles in this respect, and the costs of planning and design are typically less, so the costs of rejection are less. Following are several examples and related points:

- A facility planning process in Paradise, California “blew up” in 1992 and a proposed central collection system and treatment plant was rejected by voters of this town of 25,000, resulting in a loss of over several million dollars in planning and design costs for the centralized system (Pinkham et al. 2004).
- Wastewater system planners should be careful that plans involving annexation (e.g., to increase the revenue base for a project) could spark lawsuits from the area to be annexed, as has occurred in Missoula, Montana (Baker 2002). Lawsuits could also be brought by neighbors of a proposed facility on the basis of aesthetic, environmental, property value, and other impacts (see §10.2 on “LULUs”).
- Seitzinger (1994) illustrates the potential legal liability risk of planning the wrong system, for a Marin County community where a property owner’s association obtained an injunction to stop a sewer plan. A few onsite systems in the community were failing, so the town developed a plan for a central system and mandated universal hook-up to the sewer. The association fought against the mandated connection. Citizens argued that only failing systems should be remedied, and an onsite management zone should be created under California's Health and Safety Code. Their suit claimed that unnecessary costs of the sewer system represented deprivation of property, estimated at $40,000/home, violating 5th Amendment property rights.
- Mobile, Alabama recently chose to implement decentralized systems with subsurface dispersal to serve growing suburban areas, in part to avoid the hassles and uncertainties of obtaining a new surface water discharge for a centralized plant. Part of that hassle is regulatory, and part is locally political, as a centralized plant discharge would occur in a different watershed than the city. The utility director notes that people often do not mind dealing with their own waste, but accepting someone else’s waste is another matter. Downslope communities, far from Mobile, would likely protest any plan to receive effluent from the upslope areas closer to Mobile (Pinkham et al. 2004).
- Decentralized systems may avoid a community being forced into a substantially higher cost system as the result of an environmental review.
- Developers sometimes choose to use conventional onsite systems rather than undertake the additional effort and assume the risk of proposing a cluster system using advanced technologies, which is more difficult to have approved in some places due to regulator unfamiliarity or lack of confidence in such systems.

8.2.3 Delayed implementation risk

Decentralization benefit: *Short lead-time units of decentralized wastewater infrastructure expose a utility to the financial costs of construction delays and capital cost escalations far less than large, slower-to-build treatment plants and major collection system expansions.*

The bigger and more complicated the project, the more likely it is that delays will occur. This could result from labor problems, from litigation brought by environmentalists or project neighbors or consumer advocates concerned about costs. Costs of delays include costs escalations due to changing material or labor rates, and the additional costs of carrying debt for a longer period before the project comes on-line, as discussed in §8.1.4.

8.2.4 Operational cost risk

Decentralization benefit: *The low operating costs of many decentralized technologies expose a utility and system users to less financial risk from variation and escalation in energy and other operating costs.*

Decentralization benefit: *Even when per unit operating costs of decentralized systems are higher, overall system costs may be less susceptible to inflation and other cost escalations when decentralized systems carry less excess capacity than centralized systems.*

Increases in projected operating costs can be devastating to a project's economic viability. The importance of the risk of variable operating costs is well-documented in the energy utility industry; for instance, if fuel prices (e.g. oil) rise substantially, the cost of generating electricity goes up and a power plant may become uneconomical compared to other power sources less sensitive to fuel costs (e.g. photovoltaics or wind power).

Some centralized wastewater treatment technologies (for instance, activated sludge processes, for aeration and for biosolids dewatering) have substantial energy costs. Increasing electricity costs for such plants would reduce their economic viability relative to less energy-intensive decentralized (or centralized) systems. Of course, not all decentralized systems have low operating costs (e.g. aerobic treatment units) and some centralized technologies have much lower operating costs than conventional activated sludge plants.

Inflation can also have differential impacts on wastewater systems of different types or scale. The hypothetical community financial analysis case study—"Smallside, USA"—first mentioned in §8.2.1, included a sensitivity analysis that examined the impact of inflation on total system costs of the centralized and onsite system alternatives examined in the case study (Pinkham et al. 2004). Assuming 3 percent per year inflation in system costs, and a related 3 percent increase in the homeowner mortgage interest rate, the average annual payments by homeowners to cover operational and financing (principal and interest) costs increased by $530 for the centralized alternative, $516 for the town-owned onsite alternative, and $468 for the resident-owned onsite alternative. In this example, then, the centralized system, which had higher debt carrying costs, was somewhat more susceptible to inflation than either of the onsite system alternatives. The actual relative advantage of centralized or decentralized systems in an inflationary environment will depend upon the actual differentials in debt carrying cost and the degree to which excess capacity in a centralized system requires excess operational costs that would suffer increases due to inflation.

8.2.5 Risk of technological obsolescence

Decentralization benefit: *A decentralized strategy for capacity expansion is less likely to result in sunk costs in older technologies and instead allows for rapid response to technological change.*

Rapid technological change is endemic to most industries today, and marked change in the technology available to the wastewater sector is now occurring (Tchobanoglous 2000). In a period of flux, the smaller the units ordered and the quicker they can be implemented, the less risk. Less capital is tied up in technologies at risk of obsolescence; a larger fraction of capacity at any time will use the latest, most competitive technology; and the associated organizations can learn faster and drive continuous improvement (rather than shelving the lessons learned from one giant project for engineers to dust off a decade or two hence when the next large project is built).

Advances in decentralized technologies mean that future growth can be accommodated with improved decentralized systems, versus being "locked in" to an already-chosen centralized technology. Because decentralized technology is in many ways an “infant industry” with high potential for rapid improvement, this factor should not be overlooked. The flexibility of small, rapidly implementable units could be a key advantage for decentralized systems in times of change.

While the value of the resulting risk reduction is hard to quantify, because the nature and size of technological risk is by definition unknowable, it is prominent in the thinking of strategists in such industries as telecommunications, information technology, and energy, and should be so in the water and wastewater industries. The overall thrust of changes in these other industries is away from centralization and towards smaller technologies along with distributed intelligence and control. This strategy allows rapid adaptation to technological improvements as well as other changing conditions.

Some wastewater system planners recognize the advantage of decentralized systems in this regard. For instance, on Washington Island, Wisconsin, a centralized system was proposed in the late 1980s. Townspeople were very concerned about the costs of the plan, and when a suitable discharge site for the treated effluent could not be found due to environmental and social concerns, a new consultant who was well-versed in decentralized systems was asked to develop a new plan. He looked at both centralized and decentralized options and found the decentralized approach was less costly. Further, the new facility plan noted that a centralized system would lock-in a particular technology, while decentralized technologies could evolve and accept technology options that are more cost-effective in the future:

> … those particular strategies [recommended in the plan] merely describe one specific technological approach to implementation of the generic decentralized management concept. In the future, other methods of on-site/small-scale treatment and disposal may be found capable of adequately protecting environmental quality and public health in a more cost-effective manner. Those methods may be “plugged in” to the decentralized management strategy (David Venhuizen P.E. Engineering and Planning 1995, p. A-4).

This is exactly what happened. In 1999, the town adopted a technology that was not included in the plan. It did so when it became apparent the town needed to address flows from holding tanks during winter months (Pinkham et al. 2004).

8.2.6 Risk of regulatory obsolescence

Decentralization benefit: *Decentralized systems may allow upgrades to be focused on a small subset of a community’s capacity, saving substantial capital costs.*

Decentralization cost: *Decentralized systems may increase the transaction costs of upgrading facilities.*

Section 8.2.2 on planning risk addressed the financial risk of regulatory or public refusal of a proposed wastewater project. This section discusses the risks of regulatory changes during or after construction.

The cost, siting, and even practical availability of technologies depends significantly on regulatory requirements, tax rules, and other public policy, and ultimately larger developments in society, culture, and politics. Continuous conflicts between various groups amidst evolving social, environmental, and economic concerns make future regulations unpredictable in detail (though perhaps predictable in a general trend toward higher standards, however implemented), and thus an important source of risk. In meeting increasing demands, the advantage would appear to rest with centralized systems. Retrofitting a central plant is a single project that may offer significant efficiencies in planning, design, managerial, permitting, and construction costs over retrofitting each of many decentralized systems.[16] And a community may encounter great political, legal, and economic resistance in motivating or enforcing change for systems it does not manage or that are located on private property. However, these advantages would be reduced or overcome in situations such as the following:

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16 The costs of defining, implementing, and verifying trades or other economic actions are known as “transaction costs,” and are typically (but not always) higher on a per unit basis for multiple small transactions than for single large transactions.

- *Limited space at centralized facilities precludes upgrades that require spatial expansion of the facility.*
- *The need to upgrade performance is not uniform across the watershed or service area.* For instance, upgrades to a centralized facility may be required because of insufficient assimilative capacity at the discharge point, while upgrades to a decentralized system may not be needed because local assimilative capacities associated with dispersed, nonpoint discharge are sufficient. Moreover, upgrades to a centralized facility would have to accommodate all constituent-of-concern sources within the sewershed, while if the corresponding area were served by onsite systems, many of those systems may have adequate discharge areas and soil conditions and not require upgrades. It may only be necessary to retrofit a small number of units that are producing a disproportionate impact on the watershed, or those affecting a portion of the watershed of particular concern, though some of the savings may be offset by additional costs in determining which units to retrofit.
- *The problem is from leaking sewer pipes.*
- *Plant expansion triggers reevaluation of existing facility permits*. This allows regulators to change discharge standards, possibly resulting in additional modifications to the facility (English 2001).

Here it is important to note the concept of "regulatory lifetime." Nowadays the time between regulatory changes affecting discharges and requiring additional technologies at centralized plants is considerably less than the project lifetimes assumed in engineering or financial studies of proposed facilities. Some experts put the regulatory lifetime of large centralized facilities at around five to ten years, far less than the 20 to 30-year project lifetimes assumed in most facility plans. Existing decentralized systems are rarely required to be upgraded. Where regulations affecting them change, often the improvements need only be made when a property changes hands.

8.3 Other dimensions of financial risk

8.3.1 Direct financial risks of system failure

Decentralization cost: *Decentralization concentrates the direct financial risks (e.g. replacement costs) of system failure or inadequacy on individuals and small groups, in contrast to the insurance-like spreading of these financial risks in centralized and regional systems. This concentration of risk can impose catastrophic costs on users.*

Centralization of investments spreads financial risk across a larger user base. Even assuming proper siting, installation, operation, and maintenance of a technological system, there is always some chance the system can fail in some important way. The inherent uncertainty in the performance of a system creates a financial risk. If a system is not properly sited, installed, operated, and maintained, the risks increase further.

Failures of onsite and cluster systems result in large costs (e.g. for replacement of a septic tank or a soil absorption field) relative to the planned finances of most households. Costs can range from several hundreds of dollars for simple repairs to $20,000 or more if reconstruction or installation of an advanced onsite system is required.

Homeowners on centralized systems are exposed to some financial risk as well. Historically they have been responsible for repairs when sewer laterals on their property fail. The cost for trenching, pipe replacement or repair, backfilling, repairing sidewalks and driveways, and reseeding the disturbed area can easily exceed $3,000. In some places, insurance for sewer lateral failures is available. Insurance and warranty programs in the onsite wastewater industry are under consideration (see §11.4.9).

Relative cost streams over time affect homeowners' risks or perceived risks. Centrally managed sewer systems require only small monthly payments (typically less than a cable TV bill), which may go up as repairs and upgrades occur, but will not catastrophically change unless the system is very small. Homeowners often prefer sewers because their performance and cost streams over time are or are perceived to be less risky and more predictable (Otis 1998). Anderson and Otis (2000, p. 229) add that upon sale, financial liability passes to new owners for centralized systems, but in some places liability for previous repairs/replacements stays with previous owners for onsite system.

Interestingly, decentralized system management schemes that would lower the risks and costs of failure, particularly schemes involving government inspections, are often resisted by homeowners. Probably this results from public preferences for voluntarily assumed risks over risks or rules that are imposed. Nelson et al. (2000, p. 5-7) summarize this phenomenon:

> Undoubtedly, the common findings about risk preferences explain these concerns. Homeowners are willing to sustain the voluntary risk of catastrophic failure of their own septic system, rather than risk the dangers and pay the costs of periodic governmental inspections, which would likely reduce that risk. As John Herring wrote in a 1996 Small Flows article, "when faced with the choice between the certainty of spending a small amount of money now versus the possibility of having to spend a large amount in the future, time preferences for money reinforce the desire to avoid spending money when there is no immediate benefit."

The discussion above pertains to the risks and costs faced by the system owner(s). See §14 on reliability for the external costs of failure. And see §13 on management for information on the costs of overseeing system O&M to reduce the chances of failure.

8.3.2 Liability for system failure

Decentralization consideration: *Real impacts of failure, exposure to liability for harm to others or to penalties under law, and the financial resources to survive a finding of liability for a wastewater system failure vary in unclear ways with system scale.*

In addition to costs for replacement of a system or some of its parts, failures can also expose system owners to financial liability for damages to others or for violations of law. Information on how often decentralized system failures result in lawsuits and damage awards is not readily available. Clearly private parties can be sued for damages resulting from system failures. For centralized systems, the liability faced by local governments operating systems may be limited by legal doctrines excluding governments from certain liabilities. Nonetheless, in operating public infrastructure local governments do face liability risks,[17] including "environmental liability," defined as "a legal obligation to make a future expenditure due to past or ongoing manufacture, release, or threatened release of a particular substance or other activities that adversely affects the environment and public health." (International City/County Management Association 2001) Categories of liability under federal, state, and local statutes, regulations, and ordinances include obligations for: compliance, remediation, fines and penalties, compensation for damages, punitive damages, and natural resource damages. The following common law theories can also create liabilities: negligent misrepresentation, private nuisance law, public nuisance law, riparian rights, toxic tort, and trespass law *(Ibid.).*

Real damages, and probably monetary awards, fines, and other penalties as well, might be more limited for smaller systems than larger systems. On the other hand, the resources available to cover and recover from a damage award are also typically more limited the smaller the system.

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[17] Private companies operating wastewater systems would also face these liabilities.

8.4 Investment reversibility and salvage value

Decentralization consideration: *Some technologies used in decentralized wastewater systems may allow a project to be reversed and downsized more easily than typical centralized systems, which have a higher proportion of assets in custom-constructed components or buried in the sewer network. However, centralized treatment systems may have greater value for in-situ reuse, and the market for used conventional wastewater treatment plant components is probably stronger than that for used decentralized system components.*

Investments are reversible if they allow the investors to stop a project before it has been completed, remove components, and put them to other uses. A related notion is that of project off-ramps—a project has off-ramps if it can be stopped before it is completed and value can still be derived from the investment to date. Salvage value, on the other hand, refers to the reusability of all or parts of a system after the system has been used.[18]

Decentralized systems and small centralized technologies probably have an edge in investment reversibility on larger centralized plants. Many types of treatment units used in onsite, cluster, and small centralized systems (e.g., in the latter case, package plants) can be removed from a site and put to use elsewhere. Larger treatment plants are more likely to have a significant portion of the investment tied up in site-constructed basins, holding ponds, and even certain customized tanks or other components that cannot be moved or are only useful in the particular system for which they are designed. Centralized systems also have high proportions of their asset value tied up in deeply buried sewers, manholes, and pump stations that cannot economically be recovered and used elsewhere. However, many pumps, valves, pipes, and other components in a large system could also be removed and used elsewhere.

The notion of investment reversibility is somewhat theoretical for wastewater systems.[19] The quality that is of more realistic value is that of a project off-ramp. Much of the discussion in preceding pages touches on this quality. Systems with high degrees of modularity allow the overall project of which they are a part to be stopped at any given percentage of completion should the projected demand not materialize. The units installed to that point can be fully utilized. Less modular systems, on the other hand, which include many components of larger centralized wastewater treatment plants, often cannot be used unless they are completed. A half-completed plant of a single increment in capacity is not 50 percent usable.

Salvage value can arise in several ways. First, some wastewater systems, or portions thereof, can be put to other uses while remaining in place. Examples include a sewage treatment plant in Davie, Florida that was converted into an aquaculture (fish-farming) system (Anonymous 1997) and a proposal to convert a sewage tank into a community recreation center on the waterfront of Greenpoint, a neighborhood in Brooklyn, New York City (Lipsit 2002).

Second, wastewater systems can generate salvage value if their components can be reused for other wastewater systems. For instance, the community of Freeport, Texas substantially cut its costs for additional wastewater treatment capacity by purchasing a used package plant (Vivona et al. 1997). Pumps

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[18] The term salvage value is also used to indicate the remaining economic value of an asset or project component that has an economic life greater than the period used for an economic analysis. This value must be accounted for in order that an “apples to apples” comparison is made between options with economic lives of different lengths.

[19] As opposed to, for example the clear reversibility of many distributed electric power generation units compared to centralized power plants. Photovoltaic panels, for instance, can simply be unbolted, unwired, and moved to another site. Because significant portions of many types of wastewater systems are built in the ground, they cannot be so easily moved. Important exceptions include, for example, small textile filter units used in onsite and modular cluster systems. These are often (partially) buried, but can also be left and used above ground. Some onsite technologies are designed for use inside buildings.

and valves in many wastewater treatment plants can potentially be reused. Denver, Colorado, a few years ago sold off equipment used in its potable reuse demonstration project. An active market in used wastewater treatment equipment exists (see, for instance, the website of Aqua-Aerobic Systems, Inc., which offers used mixers, aerators, aspirators, filters, and other components; http://www.aqua-aerobic.com/resalewarehouse.html).

Conventional centralized systems and package plants may have salvage value advantages over technologies commonly used in onsite and cluster systems. Their size may make them more convertible to other uses, and because of their higher value there is more likely to be a resale market.

However, it should be noted that choosing a technology based on its salvage value would be odd and probably a false economy. It makes more sense to hedge risk by choosing a technology that offers off-ramps or reversibility.

8.5 Cost of capital

Building or replacing wastewater systems frequently requires a community, or a public or private utility providing service, to incur debt. Every dollar borrowed must be repaid with interest, so anything that reduces the amount borrowed reduces the "cost of capital." This cost is determined by three major factors: the amount borrowed, the length of the repayment period, and the terms of the debt (interest rate, points, fees, etc.).

Typically, the need for debt occurs for one or both of the following reasons:

- The community must address failing onsite systems, and the costs of replacing or repairing onsite treatment units or building a different wastewater infrastructure exceeds the immediate financial capacity (e.g. savings or disposable income) of onsite system owners.
- Growth is occurring, and the immediate financial capacity of existing residents to build infrastructure to accommodate growth is lacking.

It is important to note that many of the potential decentralized system benefits described below best suit a utility or utility-like institutional structure. For instance, they may apply to development by a local government or utility of cluster systems as an alternative to development or extension of centralized systems for a small community or an urban fringe area. They may be less relevant to dispersed onsite systems, built for and managed by the homeowner, where a utility or similar institution does not exist and may not be appropriate. Indeed some of the financial factors discussed below may work against onsite systems.

However, it is also worth noting that even dispersed rural onsite systems may be amenable to utility management. Some rural electric cooperatives, for instance, are initiating efforts to bundle onsite system services with other services such as electricity, water, and telecommunications. Certain onsite management models may be conducive to the benefits noted below. Systems built across a community under individual financing may still show some of the decentralized system financial benefits noted below when the total social cost across the community, including total financial costs paid by individuals, is evaluated in comparison to centralized alternatives. An example is provided in the following section.

8.5.1 Amount and timing of debt

Decentralization benefit: *Decentralized systems, by spreading costs over time rather than concentrating costs up front, are more likely to not require borrowing, or to require less borrowing, than centralized systems.*

Wherever community growth is part of the wastewater facility planning equation, decentralized systems can create opportunities to reduce or eliminate the need for borrowing, and thus the cost of capital. The financial benefits of seizing these opportunities are much greater than one might think. They can turn a decentralized system into a “better buy” than a centralized system that at first appears cheaper based on its net present value calculated in an engineering economics analysis. This can occur for several reasons:

- Incurring capacity expansion costs in small increments over time allows for a better match between available working capital and project costs at any moment in time. Thus, less borrowing is required. This effect is augmented by growth in working capital that should occur as more and more units come on line (in other words, as the revenue base increases).
- Reduced lead time—the time between borrowing and start of the actual useful life of the facility(ies)—reduces the up-front period during which debt must be carried. Further, shifting from one big up-front lead-time period to smaller periods occurring with periodic borrowing in the future means more of the non-productive carry period occurs later in the life of the project, reducing the net present value of the cost of debt over the full project financing period.

Small, fast units can also give a utility a longer “breathing spell” after the financial strain of a costly, prolonged project by, for instance, allowing a utility to avoid new debt for new sewer line extensions. Utilities can also use decentralized technologies to “leap frog” politically or financially risky areas, avoiding sewer extension costs and still producing revenue while systems are planned and negotiated for intervening, sensitive areas (English 2001).

As discussed in §11.1, treatment plant capacity exhibits economies of scale—costs per unit of capacity decrease as the amount of capacity increases. This often leads wastewater planners to opt for fewer, larger increments of capacity over more, smaller increments in response to growth. However, as pointed out by Pearson and Scherer (1981), smaller increments “require less initial capital outlay, with consequent savings in financing costs.” Thus, there is a tradeoff between economy of scale for larger increments and “economy of finance” for smaller increments. Pearson and Scherer note that because O&M costs, particularly staffing, are more dependent on installed capacity than actual flow, capacity-based O&M requirements must also be factored into calculation of the optimal capacity increment and timing. They show that this results in the optimal strategy having smaller, more frequent increments than would be the case without accounting for the effects of over-capacity on O&M costs.

The importance of providing a better match between demand and capacity over time should not be underestimated. Returning to “Smallside,” the hypothetical community example (Pinkham et al. 2004) described in §8.2.1 on forecasting risk, recall that the base case example was structured so that centralized and decentralized (onsite) system alternatives had the same net present value for capital, O&M, and management costs. Structuring the case study this way allowed the analysis to focus on differences in financing costs.

The partitioning of non-financing costs is somewhat different between the two alternatives, with the onsite alternative having somewhat lower capital costs but higher O&M and management costs. Moreover, the patterns of expenditures over time in Smallside are quite different between the centralized and onsite alternatives. Most importantly, the timing of capital investments is markedly different, as shown in Figure 8-4. Note that the centralized alternative requires large investments early on. These are for treatment plant capacity and an initial investment in sewer line construction. All homes within the study area are hooked-up to the centralized system in Year 1. Additional, smaller sewer extension investments occur in later years, as well as a treatment plant expansion in Year 15. Onsite system capital investments are much smaller in the early years, matching growth as it occurs and replacing old onsite systems as they fail (assumed to occur over the first 10 years) rather than all at once. Contrary to the centralized alternative, the onsite alternative requires no construction of excess capacity that the community must “grow into.”

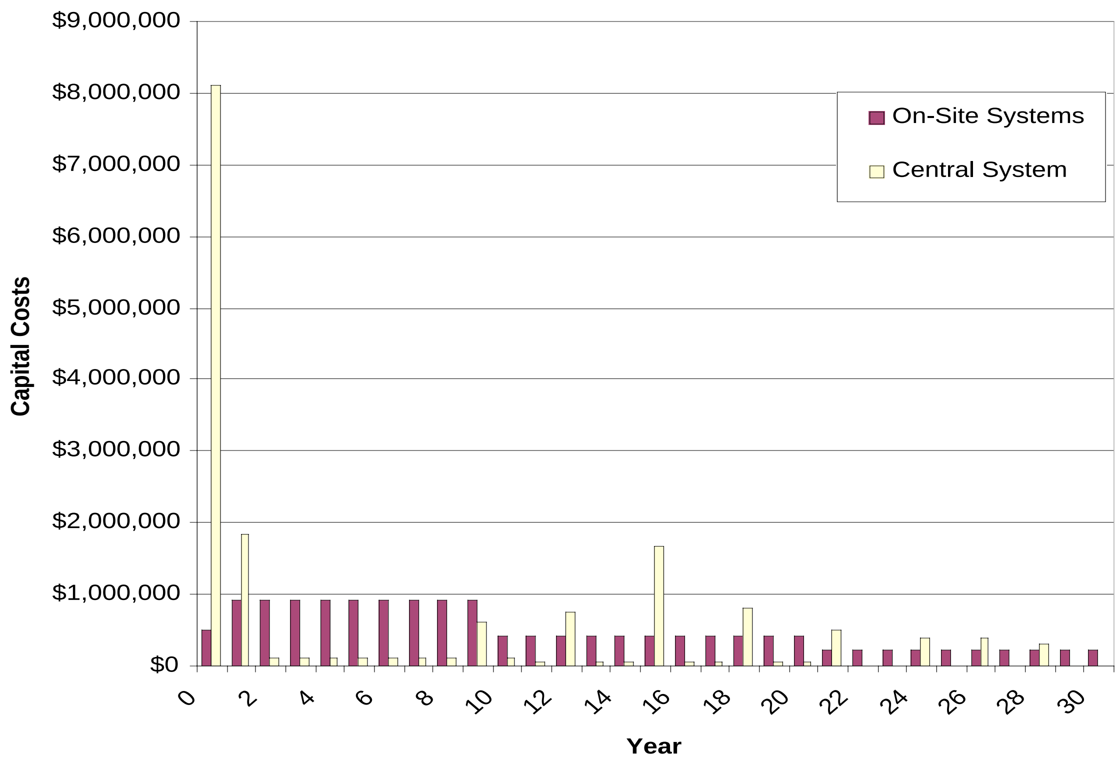

Figure 8-4: Comparison of Capital Outlays Over Time for Wastewater Treatment Options in "Smallside, USA." *Source: Pinkham et al. (2004), Figure 4-2.*

The financial implications are substantial. Under the centralized scenario, Smallside must borrow heavily in Year 0 to pay for the initial chunks of capital investment. The community then passes-on the costs to homeowners in the form of impact fees for all households that are initially and subsequently hooked-up to the sewer system. This reduces the town's debt, but one can reasonably assume that those impact fees are then rolled into first or second mortgages by homeowners, so the debt load is merely shifted. The result of the somewhat higher overall capital costs and much higher level of early year borrowing under the centralized scenario is that the total debt burden carried by the community is greater under the centralized scenario, and most importantly it is far more front-loaded. Therefore, the present value of the interest costs paid to finance the centralized alternative is much higher than the present value of interest paid to finance the onsite alternative. This is portrayed graphically in Figure 8-5.

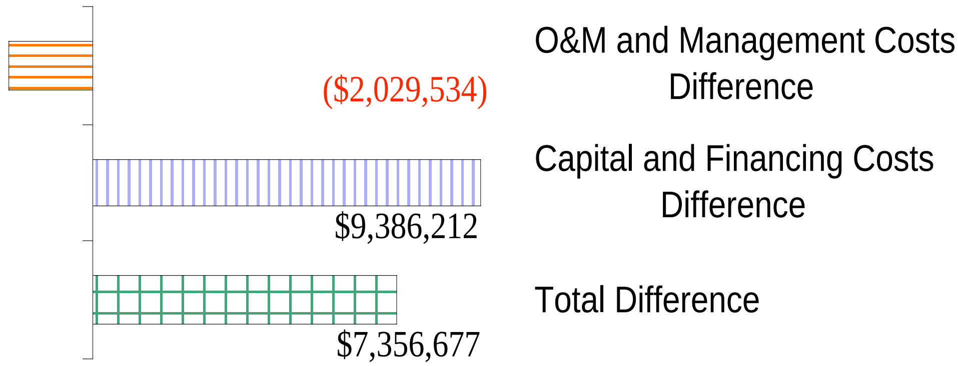

Figure 8-5: Differences in Total Lifecycle Costs for Township-Owned Options in "Smallside, USA"—Central System Costs Minus Onsite System Costs. *Source: Pinkham et al. (2004), Figure 4-3.*

The total lifecycle costs for the two options are $32,916,104 for the centralized options and $25,559,427 for the onsite options, resulting in the difference of $7,356,677. The results are essentially the same whether the onsite alternative involves ownership of the onsite systems by the town (the case in Figure 8-5) or ownership by the residential property owners. (The total cost difference for resident-owned systems is marginally greater than that shown in Figure 8-5.) In the first instance, the town requires minimal borrowing for the working capital to install onsite systems as needed, and passes on costs to homeowners in the form of annual fees. In the second instance, homeowners are assumed to finance the onsite systems on their mortgages. So in all cases, some borrowing occurs, but the borrowing is greater and much more front-loaded under the centralized alternative, resulting in substantially higher financing costs. This remained true under three sensitivity test cases: lower-than-expected growth, inflation of 3 percent per year, and a greater differential between interest rates paid by residents and by the town (assumed to be lower due to access to cheaper capital).

8.5.2 Debt terms and fees

Decentralization benefit: *By reducing borrowing increments, decentralized systems strain a utility or community's financial resources less, thereby improving its financial indicators, which may lead to better terms on debt (e.g. as a result of better bond ratings).*

Decentralization cost: *To the extent decentralized systems require a community to increase the number of times it borrows funds, they may increase the "transaction costs" associated with borrowing.*

Decentralization cost: *To the extent decentralized systems shift borrowing from a community or utility to entities with smaller assets and revenue sources (e.g. individual homeowners for onsite systems, homeowners' associations for cluster systems), lenders may perceive debt as a riskier investment and the cost of debt, for instance, the interest rates, may increase. (See also §8.6, Cost Shifting)*

One might think that the financial costs per dollar borrowed for wastewater treatment capacity would and should be the same whether capacity is provided by centralized or decentralized means. However, providing capacity by different approaches involves different types and degrees of risk. Risk is the heart of finance: the higher the risk, the higher the return required, and thus the higher the cost of capital. Differing risks for different types of treatment systems result in—or *should*, if providers of capital are astute—differing financial costs.

Decentralized should usually produce less strain on a utility or community's finance. For instance, adding one more unit to 100 similar small ones rather than one large unit to two similar big ones causes an incremental capitalization burden of 1 percent, not 33 percent. If smaller increments can be added sequentially over a period of years to match the physical capacity of a large unit, they will strain a utility's financial capacity far less at any point in time. Because small units strain financial capacity less—that is, they require less working capital—they reduce the risk of default and thus may reduce the cost of capital.

A related benefit is that the temporal distribution of costs of decentralized units can more closely match actual periods of demand growth when a community or utility's finances are likely to be in their best condition. That is, the greatest infrastructure costs and need for borrowing occur during periods of demand growth when the community is more sure of its needs, is experiencing revenue growth, and hence is better able to afford the costs of borrowing. This makes the return on investments more reliable and hence increases the value of decentralized units.

A community's financial indicators can be better under the more favorable debt (or pay-as-you go) situation of incremental decentralized investments, so it earns a better bond rating (or avoids a worse one) and therefore the borrowing costs per dollar borrowed for the decentralized program are less. Financial indicators that may be better under a more incremental, decentralized approach include:

- operating margin,
- debt to equity ratio, and
- debt coverage ratio (net revenues/debt payment).

In contrast, a worst case scenario for centralized systems is if the size of a lumpy centralized investment strains the community's financial situation to the point of reducing the community's bond rating, so the costs of *anything* the community does are now increased. A *very* worst case is that the strain of the centralized program debt and the impact to the community's credit rating means it can no longer afford to borrow for, or does not even have access to debt for other needs such as schools, etc.

8.5.3 Special sources of funding

Decentralization consideration: *Decentralized systems may be more or less eligible than conventional systems for certain grants, low-interest loans, and other alternative financing.*

Financial planning should also include a review of potential sources for outside funds. Grants, low-interest loans, and other subsidies from state and federal government programs, and sometimes from additional sources such as private foundations, are often differentially available for decentralized and centralized plans. That is, depending on local circumstances and how funding programs are set-up by specific states or other entities, either decentralized or centralized facilities may be more likely to obtain outside funding. Availability of such funding can be decisive in determining the overall cost advantage to the community of one system over another.

A variety of issues can arise when special funding assistance or innovative financing is sought:

- Decentralized systems may increase the proportion of assets under private ownership, or utility-owned but on private property, which may result in ineligibility for some low-cost funds.
- Decentralized systems may be more or less attractive to funding to private entities that have the resources to build and/or operate them, depending on circumstances and the business models of the entities themselves. Privatization of wastewater systems is sometimes seen as a way to bring additional resources to bear to solution of a wastewater problem. In such case, communities should consider the viability of different system architectures for private companies that might take over ownership or operation. Centralized systems have more of an asset value, (perhaps) clearer operational costs, and are certainly more familiar to conventional wastewater system operators, making them more attractive to companies seeking opportunities in provision of community services. On the other hand, some private utilities have been quite successful (for themselves and in terms of public service) in providing decentralized (usually cluster) wastewater services. Decentralized

systems may be more attractive to new water/wastewater market entrants, especially those who have presence on customer properties already, like electric power and natural gas utilities, telecom companies, logistics/delivery companies, etc. Companies building and/or operating decentralized wastewater systems in combination with other services will benefit from co-management economies and could potentially pass these savings on to a community. The entry of rural electric cooperatives into the decentralized wastewater service business is an important model in this respect.

- Decentralized systems are more likely candidates for "self-help," which refers to construction of systems with labor and/or materials donated by community members. As the scale of treatment and collection systems decreases, the likelihood of finding opportunities for donated time and materials increases. In contrast, larger systems require the expertise and equipment of construction contractors, and major pricing breaks are less likely. Onsite and sometimes cluster systems can in many cases be self-installed by users or community members. Neighbors (including local contractors) are often more willing to assist others when the projects become more personal in scope.

8.6 Cost shifting

Decentralization consideration: *Decentralized systems allow a community to shift project costs and financing costs to developers or private property owners.*

A substantial portion of a centralized wastewater system is originally purchased by a local government or utility. Usually, treatment plants are built on public property, substantial portions of collection systems are laid in public right-of-ways, and the government or utility typically operates and maintains the facilities (exceptions are discussed later). Private parties do usually contribute the portions of the infrastructure within specific subdivisions. Onsite systems shift all infrastructure to private property, and cluster systems likewise shift all or substantial portions of infrastructure onto private property. Thus, a developer or private property owner will usually "pick up the tab" for the entire decentralized infrastructure. This reduces borrowing needs on the part of the local government or utility. While this obviously cuts costs reflected on the utility's books, it can have a positive or negative impact on overall cost to the people of the community. Clearly, if decentralized systems cost more than a centralized system on a per capita basis, cost-shifting is a false economy. Assuming equivalent capital and O&M costs, the cost of financing comes into play, and the effect on overall costs can be positive or negative. Financing costs, and potentially overall costs, will be lower to the extent individual owners and developers have their own capital to pay for systems (they self-finance and avoid borrowing). Financing costs will typically be higher for individuals or developers if they must borrow for systems, because they do not have access to tax-exempt bonds and other low-cost financing often available to public organizations. The total economic calculus must also account for any mark-up developers add to wastewater system costs when they pass-on those costs in the price of houses sold.

A particularly important cost-shifting effect of centralized systems is that the cost of laterals is borne by private property owners. The sewer line from the house to the street is rarely installed and almost never maintained by a local government or utility at its expense. Some wastewater facility plans do not even include the costs of lateral sewers. If such a plan is comparing a centralized system to an onsite approach, it will present a faulty economic comparison. Moreover, the costs of repairing or re-installing laterals over time, which can be quite high for gravity sewers that are subject to infiltration and root intrusion, are almost never figured into the lifecycle costs of a centralized system. Communities must be sure that facility plans include *all* lifecycle costs—installation, O&M, management, and repair or rehabilitation requirements—for all options that are considered. Unfortunately, the long-term repair and rehabilitation requirements of sewer laterals and many onsite and decentralized system components have not been thoroughly researched or documented.

Another cost-shifting caveat is this: installation of centralized or cluster-system sewers and other system components by private developers who are not responsible for their long-term maintenance can result in shoddy systems likely to experience early failure. In such construction scenarios, specifications for the materials installed must be precise and the installations must be carefully verified before any components are buried.

Cost-shifting can also occur between cluster and onsite system choices. As discussed in §8.1.4, developers often have incentives to use onsite systems rather than cluster systems, in spite of the potential community benefits of cluster systems. In part this is because onsite systems allow a developer to shift capital and financing costs to builders or homeowners, instead of fronting the money for an entire development's cluster system.

8.7 Depreciation and replacement planning

Decentralization consideration: *Financial planning for any scale of wastewater system must provide for depreciation and replacement of assets.*

Even when repair, rehabilitation, and ultimate system replacement costs are considered in an engineering analysis of the lifecycle costs of wastewater service options (see §8.6 above on cost-shifting), this does not ensure these costs actually find their way into wastewater system budgets once a system is built. Too often funds are not set aside by system owners, and years later, a community must go through the borrowing cycle again.

Historically, user fees in centralized systems have not provided for the inevitable major repairs or replacement of the systems. An entire generation of Clean Water Act-financed central treatment plants and many collection systems are now reaching the ends of their useful lives, or facing huge backlogs in unperformed maintenance (U.S. Environmental Protection Agency 2002b). The risks are sewer line infiltration; sewer overflows; contamination of drinking water supplies, lakes, streams, and estuaries; violations of point-source discharges to surface waters; and other problems. It is unlikely the federal treasury can again provide the level of public subsidies in grants and low-interest loans that it did for initial construction of centralized wastewater systems from the 1960s into the 1980s.

The same critique—failure to depreciate and plan for replacement of assets—can be made of many decentralized system owners. It is rare indeed when an individual onsite system owner, or a cluster system owner such as a homeowners' association, puts aside funds through the years to pay for rehabilitation or replacement of capital assets.

Fortunately, changes in the accounting and engineering industries are beginning to force system owners to properly depreciate their assets. "GASB 34," new standards for valuation and depreciation of assets promulgated by the Governmental Accounting Standards Board, should force local governments to develop the information necessary to understand the lifecycle status of their assets, which in theory should lead to better financial planning and budgeting (Fickes 2002). As well, responsible consultants are encouraging their public and private clients to plan for asset replacement (Bell 1999; North American Wetland Engineering 2002).

Depreciation practices are also relevant to making a system choice. Communities should be aware of depreciation-related biases in the facility planning process. For instance, English, Otis, and Moen (1999) show that decentralized systems can facilitate community funding of asset depreciation, but the structure of public funding programs often discourages this because many such programs do not require communities to consider capital depreciation when analyzing affordability. As a result, apparent present worth comparisons may lead communities to pick centralized systems that are more expensive on a true present worth basis.

9 Community and watershed impacts

This chapter addresses the varying impacts on community-wide or watershed-wide social, physical, and biological systems that come with choices of wastewater system scale.

Many of these benefit and cost items are what some analysts call "NEEDS": items Not Easily Expressed in Dollars. Methods exist to put monetary valuations on some of these impacts. These methods can be quite difficult and expensive to undertake. Most communities will not want or need to quantify the economic value of some or even many of these impacts. Nevertheless, even when these impacts are not quantified, articulating them in terms of local conditions can be politically decisive. Some more and some less formal methods for qualitative analysis of these impacts are also suggested in the following text.

9.1 Growth

Decentralization benefit*: Decentralized wastewater systems expand the toolbox of strategies to manage growth and promote "smart growth": they can help avoid sewer-induced sprawl and help direct the location and form of growth as desired by the community.*

Decentralization cost*: In communities without adequate planning, zoning, and other growth management tools in place, decentralized systems can result in haphazard growth and its attendant costs.*

Decentralization benefit: *Through reduced density or improved site layout (e.g. with cluster development), decentralized systems can help reduce the proportion of impervious surface in a landscape, thereby cutting pollutant loading to surface water bodies and maintaining groundwater recharge.*

9.1.1 General impacts of growth

Growth affects communities in a number of ways:

- Growth may contribute to economic development, by increasing income received by community businesses and creating jobs.
- Growth affects the fiscal condition of local governments. New homes and businesses provide new tax revenues and represent new ratepayers for water, sewer, and other services. At the same time, growth increases the demand for those services and general public functions such as schools, police, fire protection, roads, etc.
- Growth affects local environmental conditions, impacting habitat, water quality, air quality, and other environmental resources.
- Growth influences "community character." This includes the overall "look" of a community, its "feel" and dynamism, its "sense of place," traffic levels, who lives in the community (based, for instance, on community desirability and affordability), and more.

The specific and net impacts of growth, positive or negative, depend a great deal on the spatial form of growth, particularly, whether new development is compact and contiguous with existing development, or spread out and distant. In recent decades, the costs of "sprawl" have become a matter of wide concern. Numerous studies, from the 1970s to today, have shown how growth often does not pay for itself in fiscal terms, and imposes many other costs on communities (Ewing et al. 2002; Real Estate Research Corporation 1974; U.S. Environmental Protection Agency 2001). A variety of models to predict the fiscal impacts of growth are now available (Eckhoff 2003; Moore and Muller 1991).

The environmental and social costs of dispersed growth may be even more important than its fiscal costs (Speir and Stephenson 2002, p. 67). This is because many local services (especially education) are relatively insensitive to the spatial form of growth. On the other hand, physical services such a water and sewer are highly sensitive to spatial aspects of growth (e.g, lot size, degree of dispersion of subdivisions or other grouped development, and distance from existing services), but because much of the cost of these services occurs within the boundaries of the development site (as opposed to water transmission trunk lines or sewer interceptors), much of the cost can be put directly on developers or recovered through impact fees or targeted exactions (Speir and Stephenson 2002). Therefore, while mechanisms for mitigating the fiscal costs of growth are available, environmental and social costs are more difficult to manage.

Methods and tools for assessing the environmental and social costs of growth are varied and many. Often the economic implications are difficult to quantify, but the physical impacts—for instance, increased runoff and pollutant loads from increased impervious surfaces—can be estimated. Other, topically specific sections of this report address some approaches to environmental and social assessments.

The role of wastewater systems in allowing, encouraging, and managing growth is complicated. In particular, the ways in which different architectures for wastewater services encourage “inappropriate” growth or increase the costs of growth have been hotly debated in recent years.

Following sections review the advantages and disadvantages of first, centralized systems, and next, decentralized systems, vis-à-vis management of growth and mitigation of its impacts. The discussion will make clear that much depends on perspective, and the goals of a particular community. Thus, a concluding section of this chapter addresses the need for substantial coordination between wastewater system planning and general community planning.

9.1.2 Sewers and growth

Developing or extending centralized sewers offers a number of opportunities to facilitate or manage growth:

- Many communities use control over sewer line extensions as a growth management tool. This tool works well when communities build or plan sewers where growth is desired, and require sewer hook-ups as a condition of development approval. Growth can then be diverted from unsewered areas, or areas where growth is not desired.
- In combination with urban growth boundaries, sewers can direct growth to areas contiguous or close-in to existing urban areas.
- State environmental agencies can and do use their sewer extension and treatment plant capacity permitting authority to restrict development in sensitive areas (Olenik 1995).
- Sewers make sense for communities that want growth for economic development or other reasons. They facilitate development because building and/or connecting to sewers is a familiar task for developers and well-accepted by banks and other investors that finance development projects.
- Sewers allow denser development than decentralized systems. This may be desirable to achieve a target level of development and to avoid the fiscal impacts of overly dispersed growth.

Centralized sewers may also inappropriately increase growth and exacerbate its negative impacts:

- Sewers attract growth, for better or for worse, for at least three reasons: available capacity because high fixed costs require sewers to be oversized relative to existing development; regulations that often require connection in order to develop; and increased returns on investment since sewered land can be developed more densely (Burby et al. 1988, p. 120-121).
- “Public sewage system technology directly contributes to the conversion of urban and urban-fringe land for development by facilitating a cycle of change where high user charges for infrastructure investment together with increased market value for land act as an impetus for land conversion (Hanson and Jacobs 1989, p. 170).”

- Not only do sewer extensions allow new development, and encourage it in some cases to recoup costs, but they may effectively “require” development because properties go from undevelopable to developable, and therefore are taxed at the development rate. This may force some property owners to develop their land. This phenomenon has been observed after sewer construction in Gloucester, Massachusetts, among other places (Nelson 2001).
- Residents are often very concerned about the impacts of sewer infrastructure on community character. Centralized sewers are often seen as promoting more and higher-density growth, which entails a loss of open space, more traffic, higher taxes to pay for more schools and services, and changing cultures, politics, etc. Experiences in Paradise, California (Pinkham et al. 2004) and other communities reveal the strength of the community character concern.
- Communities without a well-designed sewer master plan will find that sewer extensions happen ad hoc, based on determinations of service needs and capacity as requests are made by developers (Kruse-Stanton 2002). This is not conducive to growth management that avoids growth’s downsides.
- Sewer extensions that are not coordinated with general community plans create costs for either the community or the wastewater service provider. Raymond Burby notes that “planners have argued since the early 1960s that utility extensions should be coordinated closely with land use plans and regulation of urban growth. Without that coordination, utility extensions into areas not scheduled for development may defeat community growth management objectives—an adverse outcome for the community; or actual use of utility services may fall short of that expected by utility management—an adverse outcome for the utility (Burby et al. 1988, pp. 119-120).” Unfortunately, according the Burby, too often such coordination has been lacking.
- Sewer extensions can erode landscape patterns characterized by villages separated by open space. The state of Vermont has determined that sewer extensions “beyond the boundaries of historic and planned growth centers have contributed to scattered or strip development that is eroding Vermont's traditional pattern of compact villages and urban centers surrounded by open countryside. Such line extensions foster a pattern of inefficient development commonly described as ‘sprawl’ (Vermont Agency of Natural Resources 2002b).” Vermont’s Agency of Natural Resources has developed a growth center policy and a “Municipal Pollution Control Priority System” that establish Agency criteria for funding municipal wastewater infrastructure. Projects must only serve locally designated growth centers unless there are severe health or environmental problems outside of a municipality’s growth center(s) (Vermont Agency of Natural Resources 2002a; Vermont Agency of Natural Resources 2002b).
- By allowing increased density, sewers contribute to the water quality impacts of development. For example, on the barrier islands of North Carolina, sewers constructed to address failing septic system have allowed greater development density and development in marginal areas. The resulting stormwater runoff has further degraded coastal water quality. In 1996, the North Carolina Coastal Federation (NCCF) won an appeal of the state’s Finding of No Significant Impact for a permit to build centralized sewers in a 55 square mile area north of Myrtle Beach. NCCF argued that the sewer authority had no workable plan to address increased stormwater pollution to coastal water resulting from increased density allowed by sewer service. The state’s subsequent Environmental Impact Statement limited development density on a barrier island to no more than would occur with septic tanks. NCCF appealed the permit again in 2001 when the state failed to adequately address stormwater pollution. The sewer authority and NCCF eventually reached an agreement that included a strict limitation on the percentage of impervious surfaces in sewered areas, or construction of stormwater best management practices capable of infiltrating significant volumes of stormwater (Miller 2004; North Carolina Coastal Federation 2002).

- In addition to the water quality impact impacts of increased density, centralized wastewater systems can contribute to "hydrologic impoverishment" of ground and surface waters. Sewers may reduce ground water recharge and stream base flow through number of mechanisms described in §9.4.

9.1.3 Decentralized systems and growth

Like centralized sewer systems, onsite and cluster systems may assist or hinder growth management. A particular concern is whether advanced decentralized treatment systems contribute to sprawl and higher levels of exurban and rural growth by "opening up" additional land for dispersed development. Linkages between advanced decentralized systems and "smart growth" objectives are also of great interest at the current time.

Since at least the 1980s, it has become clear that technological change increasingly allows modern lifestyles in locations far from conventional urban services. Photovoltaics and other decentralized power sources, wireless communication technologies, satellite TV, wells and rainwater collection, and advanced onsite wastewater treatment technologies all allow "footloose" living. Rural and suburban developments without wires or pipes extending beyond the lot are increasingly common.[20]

Onsite water and wastewater treatment technologies are key to exurban development. As Arthur Nelson puts it, they have severed the "urban umbilical cord" that once linked substantial growth with connection to municipal water and wastewater services (Nelson and Dueker 1989). Conventional septic systems have long allowed safe development in many rural locations, but with advanced onsite wastewater technologies, areas with conditions not suitable for conventional septic systems—shallow soils, high water tables, steep topography, soils that percolate water too slowly or rapidly, etc—can now be developed with minimal threat to environmental and public health.

The availability of advanced decentralized wastewater systems has challenged growth management strategies in many communities and states. Historically, performance limitations of septic systems have allowed communities and higher regulators to proscribe development on certain types of sites and to set density limitations for large areas of the rural landscape. Effectively, as planner Juli Beth Hoover puts it, "In unsewered communities, planners have often relied, for better or for worse, on the ability of land to support septic systems as a *de facto* method of development regulation (Hoover 2001)." Advanced wastewater systems "are making it increasingly difficult to 'zone by septic'" (*Ibid.*). For this and other reasons, environmental groups, growth management advocates, regulatory officials, and other groups in many states have been reluctant to allow changes to state health codes and other regulations that would allow greater use of advanced wastewater technologies for onsite and cluster systems.

The particular reasons for this opposition—and the potential downsides of decentralized systems vis-à-vis growth management—are many. For instance, the debate in the 1980s in Wisconsin over allowing mound systems in addition to conventional septic tanks and holding tanks turned on several perceived impacts, as revealed in an Environmental Impact Study summarized by Hanson and Jacobs:

> Opponents to the use of mound systems … asserted at the time of the EIS that
>
> (1) mound system use would lead to increased rural development by "opening" lands for rural residential use that were unavailable with more conventional types of private, on-site systems because of site-based soil, slope, or water-table limitations;
>
> (2) in particular, the use of mounds would lead to more rapid conversion of critical land resources, such as agricultural lands;

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[20] In the extreme, even where water supply from wells or rainwater is impossible or infeasible, development is occurring. Thousands of people in northern Arizona, for instance, have chosen to live in locations requiring them to haul water in barrels and tanker trucks many miles from Flagstaff, Williams, and other communities with developed water supplies (Pinkham and Davis 2002).

> (3) the availability of these technologies would facilitate an out-migration of persons from the state's urban areas, leaving an already substantial public investment in infrastructure to be supported by those with the least ability to pay; and
>
> (4) the land development associated with these new technology sewage systems would lead to increased demands and development of public services (Hanson and Jacobs 1989, p. 169).

More recently, in the mid to late 1990s, Wisconsin debated a performance-based code that would allow many additional decentralized technologies besides conventional septic systems, mounds, and holding tanks. The proposed code would thereby allow development with onsite systems on sites with much shallower soils or depth to ground water than the then-current code allowed. An EIS was also prepared for this proposed code change, by the Wisconsin Department of Commerce (1998). The EIS determined that all onsite systems had a wide variety of development-related impacts. It found that approximately 20 million acres across the state could be subject to some type of development under the current code, and an additional 8.9 million acres could be developed under the proposed code. Effectively, the EIS found that because both the current code and the proposed code regulate by individual site, neither alternative "provides effective large-scale protection of land resources. These must be mitigated by the more direct methods described (Wisconsin Department of Commerce 1998, p. 212)." By more direct methods, the EIS largely meant local land use planning.

Additional concerns about the growth-related impacts of decentralized systems include:

- Use of low-density zoning based on limitations of septic or other decentralized wastewater systems increases the dispersion of residential and other development. Thus, larger areas are often "chopped up" by development more than would be the case for a similar number of units developed on a sewer system, which poses no density limitations.
- Larger lots and increased requirements for other infrastructure due to large lot sizes contribute to higher housing costs (Olenik 1995). Further, larger, more expensive properties pay higher property taxes. These factors may affect who can afford to live in an area, and thereby raise concerns about equity and community character.

While the potential growth management downsides of decentralized wastewater systems are many, so are the potential benefits. A number of experts believe decentralized systems, cluster systems in particular, offer important opportunities to facilitate "smart growth" approaches to development (Hoover 2001; Nelson et al. 2000). Also, for some of the same reasons that decentralized systems can create a growth-related cost—low density chopping up open space, for instance—they may produce a growth-related benefit, such as reduced impervious surfaces due to lower overall density. Much depends on the particular goals and objectives of a community.

Smart Growth and Cluster Development

Various new “movements” and approaches to development—smart growth, sustainable communities, new urbanism, farmland preservation, urban revitalization, and more—are changing the way many developers, regulators and consumers think about growth. A key objective of these movements is to reduce sprawl by encouraging infill development and facilitating urban expansion in contiguity to already developed areas. Another hallmark is increased density on parts of a development site and preservation of open space on remaining portions. A growing literature (Center for Watershed Protection 1998; Joubert et al. 2004; Nelson et al. 2000; Rocky Mountain Institute et al. 1998) documents the benefits of this “cluster” approach to development:

- Creation of viable, neighborly neighborhoods;
- Reduced per-house development costs;
- Lower costs for public services;
- Increased open space;
- Reduced land disturbance;
- Preservation of natural features of the landscape and valuable habitat areas;
- Reduced amounts of impervious surfaces;
- Reduced runoff volumes and pollutant loads;
- Maintenance of groundwater recharge and baseflow of associated streams;
- Increased marketability of homes;
- Increased property value (up to 50 percent for ponds, wetlands and other green space approaches to stormwater management that provide ancillary benefits such as walking, bird-watching, etc. (U.S. Environmental Protection Agency 1996)).

Returning to the early debates over decentralized wastewater technologies in Wisconsin, Hanson and Jacobs summarize the growth management arguments made by those who argued mounds should be allowed:

> Supporters of mound system use … speculated that mound system use
>
> (1) would lead to more compact rural land use patterns by allowing for use of land currently "skipped over" because of soil, slope, or water-table conditions unsuited to conventional on-site sewage system use;
>
> (2) would reduce pressures on the state's prime agricultural lands by facilitating development of more marginal lands; and
>
> (3) would, in fact, reduce infrastructure investment by eliminating the need for more expensive, urban-based public sewage systems (Hanson and Jacobs 1989, pp. 169-170).

Following are some additional potential benefits and advantages of decentralized systems—particularly advanced systems—for managing growth and mitigating its impacts:

- While sewers can serve the cluster development model advocated by the smart growth movement, the open spaces preserved by this development model increase diseconomies of scale in central collection systems (see §11.2.2) compared to cluster wastewater systems.
- Like sewers, advanced decentralized systems can allow increased density over conventional septics, reducing the per lot costs of providing water, electricity, roads, and other infrastructure. This increases affordability.

- Advanced decentralized systems, by facilitating more compact development relative to conventional onsite systems, may also make the fiscal equation for provision of municipal services more favorable.
- Advanced decentralized wastewater systems provide an alternative to sewers that gives communities additional options. “Using decentralized management allows communities to support a much broader range of land use patterns than either ‘zoning by septic’ or creating growth incentives when sewer lines are built. For example, advanced treatment units and cluster systems can support high-density, small-lot development in an area where sewers would support the density, but might be expensive or create unwanted growth pressures elsewhere (Hoover 2001).”
- The many varieties and performance characteristics of decentralized systems provide communities with highly flexible means to integrate planning goals and wastewater services (Hoover 2001).
- Unsewered communities can use advanced onsite and cluster systems to de-couple the location of growth from only those areas with soils suitable for conventional septic systems (Nelson et al. 2000, p. 4-12). For instance, in conjunction with zoning and other planning tools, advanced systems can help steer development toward areas with marginal agricultural soils, preserving prime agricultural land.
- Decentralized wastewater systems are “growth neutral” from a public investment perspective (Hoover 2001). That is, while centralized systems typically involve a public investment that requires additional users in order to pay for the installed capacity, decentralized systems need not involve either excess capacity or public investment.
- Given their growth neutral characteristics, decentralized wastewater systems unhook communities from “the reflexive sewer extension-growth cycle that has often led to undesirable land use patterns. Sewer lines can be extended with the best of intentions, usually to remedy public health hazards. Once done, however, new growth to tie in to the extended line becomes an expected consequence, necessary to pay user fees to cover the cost of that new infrastructure (Hoover 2001).”

A number of communities and states are using advanced decentralized technologies to both protect water quality and achieve growth management goals:

Warren, Vermont. This small, rural community used decentralized wastewater approaches to preserve its village atmosphere and limit growth. Juli Beth Hoover explains:

> In the historic Village of Warren, Vermont, home to roughly 100 households and businesses, a decentralized management program is focusing on developing lower-cost, less invasive alternatives to a planned central sewer system that had raised significant growth concerns.
>
> Warren linked wastewater management to two Town Plan goals: protect drinking water supplies, and preserve the historic development density and pattern by limiting additional growth. The Village wastewater committee and Select Board thus chose solutions that maximize the use of growth-limiting on-site septic systems, minimize expansion of the Village's small sewer system, and utilize advanced treatment units only to solve physical and environmental problems on the Village's many small, riverside lots as opposed to allowing more intensive development of slightly larger properties (Hoover 2001).

Block Island, Rhode Island. This community used advanced onsite technologies in sensitive areas to protect water quality, while also limiting growth to sewered areas through a strong comprehensive plan and sewer plan:

> Block Island (the Town of New Shoreham) is a 6,400-acre island ten miles off the southern Rhode Island. The Island has about 1,300 homes and a year round population of about 800 that mushrooms to over 10,000 persons per day at the height of the tourism season. Here the wastewater management program grew from the Town’s dual interest in managing growth and protecting its sole source aquifer. Studies show water quantity is limited, but adequate for future growth under current zoning. This includes a central harbor business/village district served by public water and sewer, with low-density (3 acre) residential development in the remainder of the Island. Both the comprehensive plan and sewer facilities plan restrict

> the sewer service area to the harbor business/village district to limit sprawl and excessive water use. The wastewater management ordinances are strongly tied to these comprehensive plan goals, which specifically call for maintaining existing, high quality waters (Hoover 2001).

Rhode Island. A manual developed by the University of Rhode Island Cooperative Extension entitled, "Creative Community Design and Wastewater Management" (Joubert et al. 2004) demonstrates how advanced decentralized wastewater treatment systems can be used to support more compact land use patterns with smaller land area requirements. This manual builds upon the South County Design Manual (Flinker 2001) developed to highlight alternative onsite wastewater treatment systems that can be used to make more compact designs practical and environmentally sound options for unsewered communities. Case studies display how alternative and cluster systems enable communities to remediate failing or substandard systems, revitalize traditional development, and enable communities to avoid pitfalls such as the high cost of sewers, loss of control over land use with intensified development pressures, and associated environmental impacts.

Chatham County, North Carolina. This community "has begun to define options for developers in booming rural areas based on water quality protection and other needs. These include bonuses for designing higher-density development that provide more open space and for designing compact, mixed-used rural communities as well. Officials recognize that the more dense developments will require innovative wastewater technologies and management and are actively exploring the mechanisms to include them (Nelson et al. 2000, p. 4-13)."

New Jersey. In New Jersey, a manual entitled "Preserving Rural Character: Land Use Planning With Alternative Wastewater Systems" promotes clustered wastewater systems for their usefulness to open space and farmland preservation (Nelson et al. 2000, p. 4-13).

9.2 Community autonomy

Decentralization benefit: *Smaller systems can help a community resist unwanted annexation or regional sewer extensions, thus maintaining the community's character, independence and control over other services.*

Local political and financial pressures can distort decision making about wastewater system options. For instance, as many cities lose population and tax base to suburban development, they can face difficulties in recovering sunk costs of public services, including those of large centralized wastewater systems. Extending or planning services such as wastewater collection can provide a rationale and tool for annexation that offers new revenue sources, or may be seen as facilitating regional growth management.

If pressures for annexation are strong, decentralized wastewater treatment options for growing areas may be overlooked. Or they may have strong appeal as a way to stave off annexation. Avoiding sewer extensions by using decentralized systems can allow a non-incorporated community to resist annexation by a neighboring municipality. The rationale for avoiding annexation would typically be maintaining political control and avoiding increased costs for public services. Even where a community is already incorporated and need not fear annexation, it may resist extension of sewers from larger regional systems in order to maintain community control of infrastructure and the character of local development. A few examples of these rationales and battles follow.

Missoula, Montana. A coalition of homeowners and landowners on the edge of this city is suing the city, county, and state over the extension of a sewer system. The extension will require annexation of the target area into the city. The plaintiffs fear the costs they will have to pay for the project and the increased taxes and regulation they believe annexation will bring. They are suing under provisions of the Montana Environmental Policy Act that require review of reasonable alternatives to state actions that impact the human environment to a significant degree (Baker 2002).

Holliston, Massachusetts. Here, a plan to construct two WWTPs to serve this growing community of 14,000 was favored over less expensive options for connection to a regional WWTP because, along with certain environmental benefits, it "would allow the town to control its own destiny with regard to wastewater disposal (Bell et al. 2000)."

Wisconsin. Wisconsin's performance-based code was resisted by the Wisconsin Alliance of Cities (among other groups) on the basis that in allowing decentralized systems in more situations, the code would create obstacles to sewer extensions and municipal annexations, which the League saw as tools for promoting orderly development and a mechanism for augmentation of local revenues (Pinkham et al. 2004).

Lake Elmo, Minnesota (Pinkham et al. 2004). In recent years, this growing city east of St. Paul has focused on cluster development and open space preservation as a way to preserve some of its rural character. Open space areas of cluster developments in Lake Elmo are typically put into conservation easements. To accomplish this style of development, developers and the city have turned to cluster-scale wastewater collection and wetland treatment systems. Lake Elmo has resisted extension of a regional sewer into the city as unnecessary and unwanted. Neighboring cities on the regional sewer exhibit the kind of high-density residential and strip development that Lake Elmo is trying to avoid. The city believes that cluster wastewater systems provide more than adequate service for the development it envisages in coming years. Lake Elmo's 2000-2020 draft Comprehensive Plan did not include the sewer extension.

The Lake Elmo story also shows the difficulties of maintaining a posture of infrastructure autonomy in a community that is embedded in a growing urban region. The Metropolitan Council, Minneapolis/St. Paul's regional planning authority, in 2002 declared Lake Elmo's comprehensive plan to be in violation of the city's commitments under regional planning and infrastructure agreements. The Council claimed that since Lake Elmo has long accepted regional largesse, such as regional investments in transportation and a large regional park in the city, Lake Elmo must also take its fair share of growth, which the Council concluded required significantly higher density in many portions of the city, and the sewer extension necessary to service that density. In the spring of 2003, an administrative law judge agreed with the Council. Lake Elmo then took its case to an Appellate Court, which ruled in favor of the Council. Lake Elmo has appealed that decision to the Minnesota State Supreme Court.

Economically, the value of employing decentralized systems to preserve community character, maintain political control, and so on is intangible but important. This value is demonstrated by the willingness of communities to pay for wastewater systems that may be more expensive than a regional solution, as occurred in Holliston, Massachusetts. It is also shown by the willingness of persons and groups to engage in legal action to preserve autonomy by opposing sewer extensions, as occurred in Lake Elmo, Minnesota. Simultaneously, defending sewer extension plans against such oppositions can impose very real costs on larger systems.

9.3 Support of local economies

Decentralization benefit: *Decentralized systems likely keep more money circulating within a local economy—supporting local income and creating local jobs—than centralized or regionalized systems of similar lifecycle cost.*

Simon Gruber of the Gaia Institute summarizes this point nicely:

> Larger, more centralized collection and treatment systems clearly involve major capital expenditures on the collection network. These costs (together with the costs of the treatment plant itself) ultimately include major interest payments as loans or bonds that are paid over time. While the principal component of these expenditures is typically invested in the community, creating jobs and purchasing some local materials, the interest portion of this flow of capital, generally, leaves the community. Similarly, over the lifetime of a mechanized WWT system, a significant portion of the operating costs of the treatment plant (and any pump stations in the collection network) goes into paying for electricity to run pumps, aerators, sludge processing, etc. Expenditures for both of these categories of costs (interest on capital investment, and

> power charges) tend to be siphoned out of the local community, going to investors and shareholders of the various entities that lend money, supply power, etc. Expenditures for chemical additives used in treatment also tend to leave the community.
>
> In contrast, a decentralized approach may tend to require lower capital investment. In some cases, depending on treatment technology (e.g., if using constructed wetlands, aerated ponds, or other systems that utilize solar energy and longer treatment periods), it can mean lower power costs over the life of the system. One tradeoff, however (and a significant impediment to decentralized thinking among many regulators and engineers), is the greater need for ongoing management, inspection and maintenance with a decentralized strategy that includes many small treatment systems. This appears to be a disadvantage, and a source of uncertainty and complexity, compared with one centralized treatment plant.
>
> However, it seems to me, the other way of looking at this problem is that a decentralized approach will, potentially, create more jobs. The inspection, maintenance, and repair of many smaller systems requires more people. Therefore, on average, a higher percentage of the total costs borne by system users, over the life of the system(s) serving a given geographic area, will go towards labor costs if systems are decentralized. And, a lower portion will go into power and interest payments.
>
> Thus, a decentralized strategy will tend to create more permanent jobs for residents of the local community, and keep ratepayers' money circulating locally, versus a more centralized approach, which sends more of the total system cost (capital and operating) out of the community. Even if the actual monthly cost to end users was exactly the same with a decentralized approach, I'm sure that most communities would choose to keep their money circulating locally, if they realized they had a choice during the initial planning process (Gruber 2002).

To the authors' knowledge, no one has carefully documented the degree to which decentralized systems are more likely than centralized systems to use local contractors, installers, and labor, or the degree to which financing and operational costs of wastewater systems stay in a community or leave it. However, these issues are well documented in other infrastructure and resource fields. For instance, studies have amply documented how expenditures on energy efficiency create more local income and jobs than equivalent purchases of power from conventional power plants operated by (usually) distant utilities (Geller et al. 1992; Goldberg et al. 1998).

Assuming quantification of types, relative levels, and purchase locations of primary expenditures (materials, energy, labor, etc.) can be accomplished (this should not be too difficult to determine or approximate), **input-output analysis** can be used to estimate impacts on local income and jobs, including "multiplier effects" as money is circulated within a local economy (Homeowner contracts with installer, installer buys materials at local contractors' supply business, contractors' supply business hires helpers, helpers spend wages on groceries at the corner store, etc.).

9.4 Hydrologic impacts

Decentralization benefit: *Decentralized systems avoid the hydrologic impacts that centralized collection systems can cause or contribute to. These include lower water tables, drawdown of aquifers, and reductions in stream base flow.*

The role of *water supply systems* in altering ground water levels and surface water flows is widely recognized. Less well known are the ways centralized *wastewater systems* contribute to the problems caused by supply withdrawals or themselves cause significant hydrologic changes:

- Collection systems prevent local recharge of ground or surface waters when they transport locally withdrawn water supplies, disposed to sanitary sewers, to out-of-basin treatment plants, or dispose of treated effluent via ocean, lake, or distant downstream outfalls.
- Collection systems experiencing significant infiltration intercept natural ground water flows and transport water to distant discharge points, often significantly reducing local ground water recharge and stream base flow support.

- Even where infiltration is minimal, collection systems may remove groundwater. It is possible that water may move along a gravity sewer line gradient but outside of the pipes themselves, particularly if gravel pipe bedding or disturbed soil from trenching is more permeable than the surrounding natural soil and subsoil. Essentially, sewer lines could in places act as "French drains."
- Combined sewer systems also intercept runoff, via inflow through roof downspouts, street and parking lot drains, foundation drains, etc., that would otherwise add to streamflow between the point of sewer inflow and the eventual treatment plant discharge, or move the water out of basin.[21]

Centralized systems also contribute to hydrologic change in an indirect but critical manner. Centralization of wastewater service beyond the cluster scale allows high-density development over large areas. Increased density results in increases in impervious surfaces. Included among the many impacts of high levels of impervious surfaces is a reduction in infiltration of rainwater and snowmelt into the soil, and attendant reductions in ground water recharge. This can impact aquifer levels and base flow of streams. These impacts are well-documented and represent an increasing public policy concern (Otto et al. 2002)

The hydrologic impacts created by the combination of high levels of imperviousness in conventional development, conventional stormwater management techniques that do not recharge ground water, and centralized wastewater systems that further intercept or transport water away from recharge zones should be understood as highly interrelated. While keeping this in mind, this section focuses on the direct role of wastewater systems. It is clear that centralized sewer systems contribute to significant hydrologic problems in many areas.

The potential contributions of decentralized wastewater systems to maintaining ground water recharge are beginning to receive attention in literature (Hoover 2001; Zimmerman 2002), though still largely as a logical idea rather than a topic of hydrologic studies. Nonetheless, in some areas of the country, recognition of the hydrologic impacts of sewers has led local and state policy makers to promote increased use of decentralized wastewater treatment systems. A few cases of impact and of action are noted below.

Coastal areas: Water supply withdrawals and transport of water through the wastewater systems to ocean outfalls, without provisions for local aquifer recharge, threatens saltwater intrusion to aquifers in many coastal locations. Some centralized systems, notably in California and Florida, reduce saltwater intrusion by recharging aquifers with treated effluent through ground injection or surface infiltration basins.

Long Island, New York: Several decades ago, installation of sewers and centralized treatment resulted in detectable lowering of ground water. Resulting reductions in stream baseflows led to development of a Flow Augmentation Needs Study that assessed ways to reduce impacts to stream flows, fish, and wildlife (Herring 2001).

On *Block Island*, off the coast of Rhode Island, improvements to decentralized systems are seen as important not only to protecting the quality of ground water, but also as a way to recharge the island's sole source aquifer and prevent saltwater intrusion, along with water conservation efforts (Joubert et al. 1999).

Metropolitan Madison, Wisconsin: In Dane County, Wisconsin, the municipality of Verona withdraws water from the Sugar River watershed and sends a portion of its wastewater to the city of Madison's treatment facility, which disposes effluent in a different watershed. This arrangement was instituted in the early 1990s to replace Verona's local wastewater treatment plant, which was approaching capacity. The regional tie-in only required a pump station and a 2-mile force main to connect to Madison interceptors, at a cost of about $2.5 million, compared to $25-30 million for upgrading and expanding the local plant. However, local residents wanted the effluent returned to the Sugar Creek watershed due to concerns over

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[21] This point is relevant to existing systems, but not to decisions about new collection systems—combined sewer systems are no longer constructed in this country.

potential instream flow reductions that regionalization could cause, including possible shoreline level reductions in a pond on Sugar Creek in the central park of a downstream community. A 10-mile long, $4.5 million line and pumping system was built to return up to 3.6 MGD to the local watershed. Annual pumping costs are about the same as they would have been had disposal been made via Madison's usual outfall, which also requires pumping. Fisheries specialists at the Wisconsin Department of Natural Resources have raised some concerns that the treated effluent might raise ambient temperatures in Sugar Creek, to the detriment of spawning trout, and monitoring of the effluent and stream is now underway to determine if this is the case. In the meantime, only 2.2 MGD of the 3.0 MGD wastewater flow generated from the Sugar Creek watershed is returned to the watershed. Also of note, within Madison's own Yahara River watershed, the wastewater system was built to avoid discharge to a series of four lakes on the river in the city. Given growth in the watershed upstream of the lakes, projections show that in the not-too-distant future there may be no flow through the lakes during years of low precipitation (Schellpfeffer 2000).

Metropolitan Boston, Massachusetts: Over the years, a highly regionalized wastewater collection system has been built to serve the greater Boston metropolitan area. The Massachusetts Water Resources Authority (MWRA) now provides sewer service to most people in the region, treats sewage at its Deer Island wastewater plant, and disposes the effluent via an ocean outfall. MWRA provides water service from a distant, western Massachusetts reservoir to a smaller portion of the region's population than is covered by the MWRA regional sewer system. Many towns have their own local water supplies, mostly from ground water. This configuration of the supply and collection systems results in much locally withdrawn water being sent out of local watersheds for treatment and disposal (Canfield et al. 1999; Pinkham et al. 2004; Zimmerman 2002). Further, I/I to sewer lines is removing water from local watersheds. Other centralized municipal WWTPs in watersheds impacted by the MWRA system also result in movement of water significant distances from its place of origin. These mechanisms of interbasin water transfer significantly impact three major watersheds in the region, those of the Neponset, the Charles, and the Ipswich Rivers, as described in the following subsections.

<u>Neponset River</u>

The Neponset River watershed is home to roughly 300,000 people. About one-half get some portion of their water from sources in the watershed, mainly municipal ground water wells. On the wastewater side, roughly two-thirds are served by the MWRA regional sewer system. The Neponset River Watershed Association has calculated that on average the balance between out-of-basin water supply inputs (+), sanitary sewer flows of locally withdrawn water supplies (-), and I/I (-), leaves the basin with a conservatively estimated net loss of 25 MGD (Neponset River Watershed Association 1998, p. 44). This translates into a total annual loss of 9.1 billion gallons transferred out of the basin by the regional sewer system, which is approximately equivalent to 23 percent of the Neponset River's annual flow (Neponset River Watershed Association 1998, p. 46). The basin's hydrology is not well enough understood for a determination of how much of the transferred water would otherwise have reached the river, but 23 percent is significant.

MWRA took another approach to assessing the regional sewer system impact. It calculated that sewer system transfers of water out of the basin were equivalent to only 10 percent of the total annual rainfall in the basin. This seems a small figure, but when one considers that 40–50 percent of annual rainfall is transferred back to the atmosphere via evapotranspiration, and that groundwater recharge is also reduced because of impervious surfaces and storm drainage systems, the relative importance of the 10 percent figure increases.

Reductions in Neponset River flows cause rising water temperatures and reduced dissolved oxygen, weed growth on the river bottom and mobilization of nutrients as a result of increased sunlight penetration, and drying out of wetlands. Recreation has been constrained by low flows and high bacteria levels during summer months. Water temperatures of 91° F forced one industrial user to convert to refrigeration after previously using river water for non-contact cooling (Neponset River Watershed Association 1998, p. 3). (Industrial discharges probably also contribute to elevated temperatures.)

Several mechanisms cause the interbasin transfer, according to the watershed association's study. Transfer of water to other watersheds via the local water withdrawal and distribution system is a small portion. So too are transfers of locally withdrawn water as sanitary sewage via the regional collection system. The bulk of the transfer is due to collection system I/I. The municipal systems feeding into the MWRA system are quite old and many are in poor condition. Five Neponset Basin communities rank in the MWRA "top ten" of communities with the highest rates of I/I, measured as a percentage of total flow. On average, 52 percent of all wastewater flows from basin towns was infiltration, and 12 percent was inflow between 1995 and 1997 (Neponset River Watershed Association 1998, pp. 33, 44).

Water quality monitoring data found "only very limited water quality impact from failed septic systems in the Neponset Basin," contrasting with "severe water quality impacts from failed and overloaded sewer systems" which widely replaced septic systems over the last several decades, according to the Neponset River Watershed Association (1998, p. 31). However, MWRA notes that many of the worst areas of septic system failures have been sewered, so the comparison is not entirely fair. As well, the agency points out that impacts from sewer systems are infrequent, typically occurring during very high flows, when stormwater would have degraded water quality anyways. Contamination from septic systems can occur year-round and, while not as dramatic as sewer failures, can be substantial.

Charles River

Flows in the Charles River are reduced, with negative impacts on water quality, although overall water quality has improved dramatically in the 1990s in part due to the new Deer Island plant. The MWRA regional sewage collection system transports ground water out of basin through I/I. In addition, sub-regional municipal wastewater collection and treatment systems, which discharge wastewater within the basin but bypass long reaches of the river, are believed to contribute to localized groundwater depletion and low-flow conditions. In the Charles River watershed, between 60 and 65 percent of instream flow comes from groundwater recharge (Zimmerman 2002). The Charles River Watershed Association and other organizations have given considerable attention to the disconnection between rainfall and groundwater recharge caused by impervious surfaces and by I/I to sewer collection systems in the watershed.

On the other hand, the Charles benefits from inputs of water to the watershed via the MWRA water supply system. In towns that receive drinking water from MWRA's western Massachusetts reservoirs, but do not utilize the MWRA regional sewer system, imported water is added to local watershed budgets through onsite, community, or sub-regional wastewater systems. This input may prevent the Charles from having low-flow problems as serious as the Ipswich River does.

Ipswich River

The Ipswich River basin is mostly outside the MWRA service area except for a few locations near the headwaters of the river in the town of Wilmington. In the Ipswich, local supply withdrawals coupled with centralized wastewater collection systems (including but not limited to MWRA) have actually resulted in the river drying up in some summers, producing significant fish kills (Armstrong et al. 2001). Yields of local ground water wells may have been reduced as well.

Recent policy initiatives in Massachusetts are beginning to address interbasin water transfers via sewer systems. The state's Interbasin Transfer Act, initiated due to large scale surface water supply developments proposed in the 1970s, has recently been applied to proposed development of a municipal ground water well in Canton, a town in the Neponset watershed which is on the MWRA's regional sewer system. The act calls for implementation of "all practical alternatives" before transfers are allowed. Localized wastewater treatment, including decentralized systems, could support this standard. Also, the Massachusetts Department of Environmental Protection has recently developed new guidelines for sewer facility planning in its “Comprehensive Wastewater Management Plan” (CWMP) process. The guidelines identify a range of options for evaluation when sewer extensions are planned, including leaving some areas on onsite systems or going to cluster systems (Cook 2000; Lyberger 2000).

Bell et al. (2000) report on a CWMP facility planning effort and Massachusetts Environmental Policy Act process for the town of Holliston, Massachusetts, in which maintenance of local streamflow was a decision factor. Based on density, soil conditions, and other factors, a needs analysis determined which portions of the town, population 14,000 and growing, could be served by conventional septic systems, and identified “needs areas” where other wastewater treatment was indicated. Alternatives examined for needs areas included advanced onsite systems, communal systems, one or more new, local (in-town) WWTPs, and transmission of wastewater to an existing regional WWTP. Cost, environmental, and other factors were considered in the alternatives analysis. Two options for transmission of all of the 1.1 MGD of wastewater from the needs areas to a regional WWTP were found to be lower in cost than four other alternatives. However, the study recommended a more expensive option (by 9 percent or 14 percent compared to the regionalization options) that would keep all wastewater in-town. Two WWTPs would be built, and disposal would occur at four subsurface groundwater dispersal sites. This alternative was preferable because it “would allow the town to control its own destiny with regard to wastewater disposal. It would be the town’s most environmentally sound option, and would maintain stream flows in the Upper Charles River Basin and insure the sustainability of the Town’s water resources for centuries.” According to the article, the Town expected to proceed with the recommended plan.

The hydrologic effects noted above can produce or contribute to a variety of economic costs:

- increased water pumping costs as ground water tables recede;
- increased water treatment needs with saltwater or brackish water intrusion to aquifers or coastal streams;
- reductions in property values where water supplies are lost or threatened;
- replacement of local ground water supplies with other sources if ground water becomes too contaminated or deep;
- increased POTW treatment costs as assimilative capacity is reduced when stream flows decrease;
- reduced fishery and recreation value due to reduced stream flows or compromised water quality because of reduced flows;
- loss of wildlife habitat and water filtering services as wetlands and riparian zones decline.
- increased costs for industrial and other cooling systems as low-flows increase water temperatures (a plant on the Neponset River recently had to switch from water cooling to refrigeration) (Neponset River Watershed Association 1998, p. 3).

The degree to which decentralization can reduce hydrologic and resulting economic impacts relative to larger scale systems depends on a number of factors:

- Local soil and geologic conditions affecting infiltration and runoff rates and connection of subsurface water movement to deeper ground water and aquifers.
- Connection of local ground water to surface flows—is the ground water “tributary” to local water bodies?
- The level of imperviousness in the local area and the degree to which distributed subsurface introduction of treated wastewater effluent to the local hydrologic system can compensate for stormwater runoff losses from the ground water system.

Based on local conditions, onsite systems may provide an important ground water recharge and stream flow support service, or it may be necessary to concentrate wastewater volumes in a smaller number of locations where most ground water recharge is known to occur.

The first step in valuing hydrologic impacts caused or avoided by an existing or proposed wastewater system is to estimate the magnitude of the hydrologic change itself. Horn et al. (2000) have developed a methodology for improved estimation of infiltration and inflow and interbasin transfer of freshwater and wastewater.

None of the persons contacted for this study were aware of any studies of the economic impacts associated with hydrologic alterations produced by sewer systems. Nor did they know of any efforts to assess the costs decentralized wastewater treatment systems can avoid through reducing alterations to hydrologic regimes by facilitating water reuse to displace water supply withdrawals; avoiding use of large collection systems and the out-of-basin transfer of I/I water and locally supplied sanitary water associated with them; and directly recharging local ground water, via soil absorption as a part of treatment or as a result of reuse. In short, while the water *quality* implications—positive and negative—of wastewater systems are the subject of a voluminous environmental and economic literature, the issue of the hydrologic impacts of sewerage appears to be in early stages of recognition by wastewater professionals, regulators, and environmentalists.

However, values could be extrapolated from water supply studies that place costs on reductions or replacement of water supplies. A substantial body of literature on non-market valuation of the assimilative, recreational, and habitat values of instream flows could also be applied.

Decentralization consideration: *Direct streamflow augmentation from any scale system may be beneficial or detrimental**.***

It is clear that effluent discharges from wastewater systems at the centralized and regional scale can have a significant affect on surface water hydrology. The effects can be many:

- Wastewater effluent can be expressly used for low-flow augmentation. For instance, in a small urban stream in San Antonio, Salado Creek, low flows were less than 1 cfs due to drought and depletion of groundwater. Augmentation with treated wastewater raised base flows year-round to 3 cfs (Water Environment Research Foundation 2001).
- Wastewater effluent may support streamflow and water quality by happenstance rather than design. For instance, in the upper Charles River Basin in Massachusetts, a WWTP contributes an annual average of 5 cfs to the river. Including this flow, the estimated median flow for the river at the plant is 19 cfs. Often the quality of the wastewater effluent exhibits higher dissolved oxygen and lower nutrient levels than the ambient streamflow. Also, the effluent stabilizes flows downstream of the plant during low flow periods. This occurs because water is drawn at such times from reservoirs and aquifers, reducing the need for surface water withdrawals (Gerath et al. 1992).
- However, the discharge at this same plant exhibits unnatural diurnal fluctuations, which produce variation in flow velocity and water level throughout the day. These variations may be more damaging to fisheries than extended periods of low flow (Gerath et al. 1992).

The same sorts of impacts could occur with decentralized systems using surface water discharge, though such situations are rare. Decentralized systems typically use subsurface discharge to ground water. Decentralized systems could be designed for surface discharge to support streamflow if the situation warranted.

In general, support of stream base flow through recharge of groundwater is often environmentally preferable. This approach mimics natural hydrology and provides additional benefits such as increased pollutant removal and maintenance of ground water levels affecting human water supply and natural systems alike. In the Holliston, Massachusetts facility planning process described earlier, the

Massachusetts Department of Environmental Protection expressed a preference for discharge of highly treated wastewater to groundwater, rather than to surface water. The DEP believes that groundwater discharge provides better support of base flows in the Charles River than surface discharge (Bell et al. 2000).

9.5 Surface water quality

Decentralization consideration: *Smaller wastewater systems may have a more or less impact than larger systems on surface water chemistry and ecology, and thereby create economic implications for communities, depending on many factors.*

This section focuses on the environmental impacts of wastewater systems on surface water quality, and the economic costs and benefits of those impacts. Impacts on ground water quality are much more a public health matter than an environmental one—except insofar as ground water eventually reaches surface water—and are therefore handled in §9.7 on public health. Also, the question of system failures and resulting environmental impacts is taken up in Chapter 14 on reliability, vulnerability, and resilience of wastewater systems. The following discussion assumes properly managed wastewater systems that consistently achieve their expected pollutant reduction performance levels.

The impact of wastewater systems on surface water quality is a complicated subject. To begin, it is important to remember that all wastewater systems contribute pollutants to the environment. Mass loadings from a system will depend on the treatment technology used and its ability to remove particular pollutants from wastewater, and what is done with those pollutants after they are removed (e.g., biosolids disposal). The relative cost-effectiveness of different scale systems in attaining a particular level of pollutant removal is a matter that can be addressed with the methods of **engineering economics** and **cost estimation**, including the concepts and tools discussed in §16 and §17.

The question addressed in this section is different, and multi-faceted:

- how does system scale affect the release of pollutants to the environment,
- and thereby affect the water quality impacts of wastewater systems,
- and thereby create economic implications for communities?[22]

We begin by noting that a wide range of pollutants in wastewater can have environmental impacts in surface waters. They include:

- *Conventional constituents.* Most notable are nutrients, particularly nitrogen and phosphorus in their various forms. Organic materials are also important because their stabilization by microbes removes oxygen from the water column, potentially harming other organisms.
- *Non-conventional constituents.* These may include metals and other organic or inorganic compounds; for instance, petrochemicals and solvents poured improperly disposed of to the wastewater collection system, or other industrial chemicals.
- *Emerging constituents of concern.* These include a wide range of pharmaceuticals (e.g. antibiotics, estrogen in birth control pills) and their byproducts that are processed and excreted by human bodies, as well as chemicals in personal care products. Many of these compounds are bioactive in the environment. There is particular concern about impacts on the hormonal (endocrine) systems of organisms.

Detailing the nature of wastewater constituents and their impacts on the aquatic environment and creatures that live in or around water bodies is not within the scope of this study. For information on

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[22] E.g., eutrophication of a water body leading to reduced property values.

conventional and non-conventional constituents, wastewater engineering texts (e.g. Crites and Tchobanoglous 1998; Metcalf & Eddy Inc. et al. 2003) and aquatic chemistry and ecology texts provide substantial discussions. The literature on emerging constituents of concern is steadily increasing, and some useful reviews are available (e.g. Daughton and Ternes 1999; Huang et al. 2001; McGovern and McDonald 2003)..

Discerning the relative pollution and impact produced by wastewater systems of different scale is complicated. Technologies, performance requirements, and other factors affecting effluent may vary greatly, making the effects of scale hard to isolate. The following discussion attempts to “pick apart” the many dimensions of the question posed above in order to focus on the effects of wastewater system scale.

For starters, assume that centralized and decentralized technologies under consideration for a community produce effluent of the same quantity and with the same concentrations of the constituents of importance. In such a case, the mass loadings from the service area would be the same regardless of wastewater system scale.

However, the distribution of discharges would be different, perhaps ranging from one to hundreds or thousands of discharge points. Assume all are surface water discharges. Arguably, a more decentralized system would make better use of the assimilative capacity[23] of the environment because the pollutant loadings would be spread across a larger area, resulting in reduced loadings at any one point compared to a more centralized system with substantial point loadings at one or a few points. Further, Adams et al. note that effluent quality varies stochastically, even assuming a wastewater system continuously meets performance requirements, so decentralized systems have an advantage because…

> The aggregate result is that the receiving waters may be used to dampen the fluctuating performances of the many plants while maintaining acceptable point loadings of waste discharges throughout the receiving water system. That is, the more broadly distributed pattern of wasteload releases subjects the receiving water to more numerous but much less severe impacts (Adams et al. 1972, p. 677).

In practice, however, the effect of distributing the load and its stochastic variation is not so clear. Different release points will have different assimilative capacities, depending on the volume of the receiving water and other factors such as water temperature, natural water chemistry, and biota. Therefore, while the gross impacts may be less because of distributed use of assimilative capacity, there may be specific local impacts of concern.

Next, continue to assume the same effluent concentrations, but, more realistically, assume the centralized system has a surface water discharge, and the decentralized treatment units discharge to the soil. Here a system boundary issue must be addressed. Is the focus the effluent concentration before or after the treatment that occurs in the soil? Assume first that the effluent concentrations of the decentralized units are the same before discharge to the soil as the concentrations released to surface water by a centralized system (which is technologically and in many cases economically possible). In this case, the decentralized system will clearly have substantially less impact on surface waters than the centralized system. Even assuming all effluent from the decentralized units reaches surface water (not usually the case), substantial additional treatment will have occurred in the soil before the effluent reaches surface water. In short, this is because the physical and biotic environment in soil has a far greater capacity to breakdown, take up, transform, or otherwise neutralize pollutants than the physical and biotic environment associated with surface water. Here again, however, it is possible that some localized impacts resulting from the decentralized system could occur.[24]

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[23] The ability of natural systems to breakdown, take up, transform, or otherwise neutralize pollutants without dramatic negative effect on the environment.

[24] This potential is why proper siting and design of decentralized wastewater soil absorption fields is so important and is carefully prescribed in most codes and regulations on the use of decentralized systems.

Now, assume instead that the pollutant concentrations in decentralized system effluent match the concentrations in centralized system effluent only after treatment within the soil absorption system. Then the impacts on surface waters follow similar logic to the first, all-surface-water discharge case: a decentralized system architecture will spread loadings over a larger area, reducing loadings at any one point in the surface water system, and damping the impact of stochastic variation in effluent quality. However, the decentralized system is likely to have less gross impact because additional assimilation occurs in the subsoil below the wastewater soil absorption system and even in the ground water, prior to surfacing of the ground water.

Next, relax the assumption that decentralized and centralized systems have the same effluent pollutant concentrations. This is reality. Typically the technologies and therefore the pollutant reducing performance of legal centralized and decentralized options for any particular community are substantially different. At this point, the comparison of centralized and decentralized systems' impacts on surface water becomes very difficult. Now the questions become ones like: assuming lower treatment values for a decentralized system, is release of a smaller load of nitrogen to surface water more or less harmful to the surface water than release of a larger load of nitrogen to the soil and the underlying ground water that eventually reaches surface water? One can no longer use generalizations such as the greater assimilative capacity of soil than water. Now the details of the relative fate and transport of pollutants in surface water and in the soil/ground water system must be considered (for a thorough review of the latter for nitrogen and phosphorus, see Gold and Sims 2001). The techniques of comparative risk assessment must be applied (Jones et al. 2001; Jones et al. 2004). No generic advantage or disadvantage for centralized or decentralized systems can be claimed.

Where pollutant loadings are enough to cause a surface water quality problem, two types of economic implications arise:

- "Direct" economic impacts of the water quality issue; e.g., eutrophication of a water body leading to reduced property values; and
- Costs and benefits of remediation and/or prevention.

In addressing the first type of economic impact, note that any economic impacts will also be variable, depending on the situation. Thus the economic analyst must address economic variability on top of environmental variability.

In addressing the second type of economic impact, the question becomes one of the relative costs and benefits of: a) increasing centralized or decentralized treatment levels, b) replacing decentralized systems with centralizing treatment, or c) taking other management actions. As a first step in the analysis it is important to assess the relative contributions of the pollutant of concern from all possible sources in the watershed: decentralized systems, centralized treatment systems, sewer leakages, agriculture (animal manure, fertilizers, etc.), fertilizer use in urban or suburban landscapes, wildlife, atmospheric deposition, etc.

To summarize, assessing relative economic impacts related to water quality across a range of wastewater system scale is complicated. Thus this report classifies this issue as a "decentralization consideration." No clear trend favoring smaller or larger systems is evident.

In considering this issue on a local watershed basis, many additional points beyond those raised above are potentially relevant. A few follow:

- In general, for any wastewater system, greater pollutant removal rates require higher capital and operating costs (see §11.1.2). Because nearly all treatment systems exhibit economies of scale, increasing pollutant removal requirements will tend to favor more centralized systems. As treatment requirements become more and more costly to meet, the economy of scale differential between large and small treatment systems becomes more likely to more than offset diseconomies of scale in collection.

- Pollutant sources and their relative importance can sometimes be surprising. For phosphorus, often stormwater runoff is a substantial source, sometimes the most important one. For nitrogen, atmospheric deposition of nitrogen from automobile exhaust and other sources is often significant. As an example, Voinov et al. (2004) investigated anthropogenic nitrogen sources to the Solomon's Harbor watershed in Calvert County, Maryland, and developed a sophisticated model of the fate and transport of nitrogen within the biomass, soil, ground water, and surface water of the watershed. Their results are shown in Figure 9-1. Atmospheric deposition and suburban fertilizer use were larger nitrogen sources.[25] Given that retrofitting nitrogen-reducing equipment to all or most septic systems in the watershed would be very costly, and atmospheric sources cannot be substantially addressed at the county policy level, this study suggests that management of suburban fertilizer use may be the highest leverage and perhaps least costly strategy to address nitrogen enrichment of the harbor. The importance of atmospheric sources of nitrogen has been demonstrated in other watersheds as well.

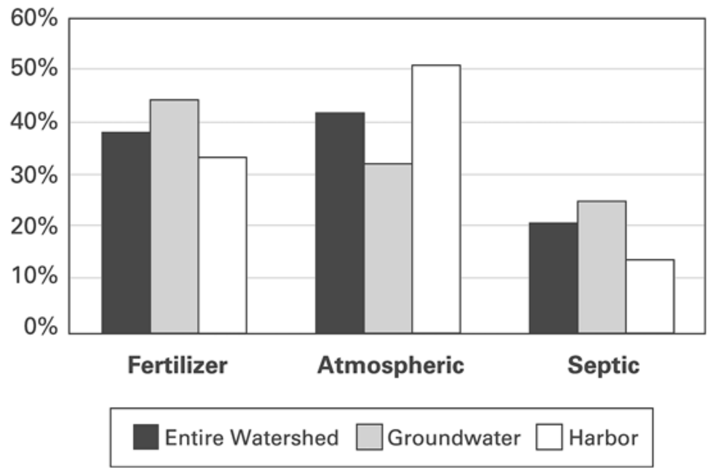

Figure 9-1: Proportion of Nitrogen from 3 Sources Over 5 Years to the Watershed, Ground Water, and Harbor of Solomon's Harbor, Maryland. *Source: Adapted from Voinov et al. (2004), Figure 4. Courtesy of Alexey Voinov.*

- Pollutant flows, once in the natural system, are subject to buffering and time lags that affect environmental impacts and have economic implications. For instance, St. Albans Bay in Vermont's Lake Champlain has yet to see water quality improvements from a substantial investment in the 1980s for a wastewater treatment plant to remove phosphorus. Loads to the bay have been significantly reduced but internal loading from phosphorus retained in bay sediments continues to create a eutrophication problem, which is now not expected to improve for another 20 years. Similarly, ground water can have a huge buffering capacity; for instance, accumulating pollutants for years before release to surface water, and prolonging release even once a pollutant input stops (Voinov et al. 2004). Because of discounting to reflect the time value of money, distant future benefits from management actions affected by time-lagged pollutant flows will have reduced economic value and may look uneconomic in comparison to near-term pollution reduction costs.

- There is some evidence that leaking sewer pipes are a much greater source of ground and surface water contamination in some areas than are septic systems (Gerba 1998). Sewers provide no septic

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[25] All models have uncertainties. The appropriate caveat here is that these results somewhat contradict previous loading estimates for the watershed, and depend significantly upon certain nitrogen transport assumptions. Nonetheless, the results are considered important by local residents and officials.

tank-like treatment. Amick and Burgess (2000) found that substantial portions of the U.S., particularly in the West, have relatively shallow sewers and low ground water tables, resulting in positive hydraulic gradient from sewer pipes to ground water. They reviewed several studies that estimated exfiltration rates at 2,417 to 77,745 gallons per inch diameter per mile per day, or 1.4 to 44.3 million gallons per day for a city of the size and sewer condition of Albuquerque, New Mexico (11 of the 14 calculated rates were between 3.0 and 9.8 MGD). Amick and Burgess point out that even in areas with high ground water tables (where infiltration is a common and recognized problem), exfiltration may occur from house laterals, which are typically shallower than sewer mains.

- Centralized treatment may be advantageous if wastewater can be moved from an impacted watershed (perhaps one for which a Total Maximum Daily Load has been established) to another watershed.
- A pollutant reduction benefit of decentralized systems may occur where adopting decentralized treatment means larger-lot zoning than would be the case with centralized treatment. The lower population density can mean reduced pollutant loading per acre. (Some communities “zone by septic” rather than facing land use planning directly. This may reduce loading but also has other costs: increased land costs per home, increased wildlife habitat fragmentation, and more. See §9.1.) However, it is important to note that the loading benefits of large lots can easily be outweighed if driveways are particularly large (increased impervious surface) and large, over-fertilized lawns are present.
- As far as non-conventional and emerging constituents of concern, it is possible that decentralized systems using soil dispersal have an advantage over centralized wastewater treatment. Antibiotics, for instance, are known to pass through conventional wastewater treatment plants (Huang et al. 2001; Mulroy 2001). The soil may be a more effective medium for neutralizing these and other contaminants before they reach surface water (Tchobanoglous 2001).

Valuation of the costs of surface water quality impairment or the benefits associated with management actions to reduce impairment typically requires the methods of **economic valuation of non-market goods and services. Contingent valuation** is a particularly useful methodology. Gren (1995) applies it to valuation of constructed wetlands for reducing nitrate contamination of groundwater and nitrogen-based eutrophication of coastal waters in Sweden. McMahon et al. (2000) apply the method to estimating the benefits, in terms of household willingness to pay, of replacing unsatisfactory onsite systems with sewers in southeast England. McDonald and Johns (1999) apply the technique in an urban setting (Bogota, Columbia) to valuation of elimination of foul odors in the Bogota River, improved visual quality of the river, and elimination of public health problems from development of a primary and secondary wastewater treatment plant. **Hedonic pricing** is also quite useful; Boyle and Kiel (2001) provide a review of applications to water quality.

Van Ryneveld et al. (2001) have developed a comprehensive methodology for: a) estimating the cost of water pollution from alternative sanitation scenarios, and b) assigning a financial cost to the environmental impact of different sanitation systems. They apply their methodology to evaluation of onsite waterless sanitation and conventional waterborne sanitation for a province in South Africa.

9.6 Other environmental impacts

Decentralization benefit: *Installation and operation of decentralized systems are likely to cause less disturbance to riparian zones than larger sewer systems.*

Conventional sewer systems typically follow streams and drainageways, because these topographic low points maximize the efficiency of connection for a gravity-flow sewer while minimizing trenching depths. In so doing, they often substantially disrupt drainage and riparian corridors—zones of high ecological value—especially in the near term during construction, but also in the longer term with disruption of soils and following colonization by pioneer plants not formally found in these zones, maintenance access, sewer lines offering groundwater drainage routes, and so on. Some environmental advocates even accuse sewer construction of turning riparian corridors into "sacrifice zones" (Cook 2000). Trenchless sewer installation technology offers ways to reduce impacts on riparian zones or other sensitive environmental areas, and has been used for this purpose in Chelmsford, Massachusetts, although the application was for two inch low pressure sewer lines and a six inch force main, rather than conventional gravity sewers (Balan and Pedersen 2000). The Rivers, Trails, and Conservation Assistance branch of the National Park Service has published a resource book on the value of protecting riparian and greenway corridors (Rivers Trails and Conservation Assistance Program 1995).

9.7 Public health

Decentralization consideration: *Smaller wastewater systems may generate greater or lesser public health risks than larger systems, depending on regulations, enforcement, technology, design and construction, O&M, and other factors.*

Public health problems resulting from release of treated or untreated wastewater to the environment have historically been due to:

- pathogens (bacteria, viruses, and protozoa) in ground or surface water; or
- nitrate (which is most hazardous to infants) in ground water.

Historically, regulations to address these problems were driven by the results of unhealthful conditions and based on rudimentary information about the fate and transport of pathogens and nitrogen in the environment. For decentralized systems, the means of addressing pathogen problems were to ensure that wastewater had adequate contact with the soil in a leachfield (a wastewater soil absorption field, or WSAS), in which most pathogens would be neutralized through biological and physical processes. Permeable soils with deep water tables were used as they worked best. Land that did not have appropriate soil conditions was zoned out of the developable land base. This was an easy regulatory solution. Nitrates created a different problem, and without sufficient dilution rendered wells undrinkable. This was one driver for development of better decentralized wastewater technologies.

Regulations have been slow to react to technological changes that allow wastewater to be treated before it is introduced to the soil. Regulations have largely continued to focus on the soil/wastewater interface and have failed to address many of the other requirements necessary for advanced decentralized wastewater systems (and even conventional septic systems) to function properly.

System design may address higher treatment needs, but often fails to adequately account for environmental factors such as damp or freezing conditions, or for infrequent O&M, the lack of qualified maintenance providers in many places, power outages, use of systems to dispose of paint or other harmful chemicals, and inadvertent damage from landscaping activities—all of which are just some of the things that can cause a system to malfunction and create a public health problem. The decentralized wastewater industry is starting to address some of these issues through the development of performance standards, but it will be some time before the industry and regulators can sort it all out.

Therefore, from a public health standpoint it is critical that O&M be provided on a regular basis, and that systems be inspected upon construction and from time to time to identify other threats to proper functioning. Additional oversight and management activities are necessary as well. The U.S. EPA has identified 13 management program elements (see Table 13-1), all of which must be addressed in some effective manner if proper functioning of decentralized systems is to be ensured.

In the case of conventional septic systems, management programs can be quite simple yet highly effective in ensuring achievement of the somewhat limited—but in many case adequate—performance potential of septic systems. More advanced technologies will require better design, installation, operation, maintenance, etc., and so require more intensive management.

As for centralized systems, they generate similar concerns. The technologies are only as good as the quality of their installation, operation, and maintenance. A somewhat stronger regulatory apparatus exists to oversee these and other activities necessary for the proper functioning of wastewater systems over certain size thresholds, particularly systems with surface water discharges. The thresholds vary state-to-state from a few thousand gallons-per-day upwards. Nonetheless, operators of centralized sewer and treatment systems in many communities struggle to maintain compliance. The U.S. EPA, states, and the industry are making substantial efforts to help centralized utilities develop and maintain the necessary technical, managerial, and financial capabilities to ensure acceptable system performance.

The impacts of system failures are addressed in Chapter 14. Failures can be considered to encompass older decentralized systems that were allowed under older regulations but are now considered inadequate; for instance, cesspools and straight pipes. Such systems have been responsible for serious public health problems. So have outdated centralized technologies such as combined sewer systems. The problems caused by decentralized systems that met old regulations but are not adequate vis-à-vis current health and environmental concerns should not be used to denigrate the viability of decentralized wastewater technologies, because on a going-forward basis, such systems are no longer permitted and are irrelevant to wastewater technology choices facing communities today. Of course, communities face choices about what scale of system should be used to *replace* antiquated, inadequate systems. But the past performance (or lack thereof) of the systems being replaced is irrelevant to the current decision.

As with the impacts of wastewater systems on surface waters, determining the relative impact of different scale wastewater systems on public health is difficult. However, current regulations regarding both centralized and decentralized wastewater systems are probably more strongly protective of public health than they are of environmental health. If proper enforcement and management occur, wastewater systems should protect public health to the degree that current regulations are adequate.

At the same time, it should be noted that systems that meet current regulations and are properly managed may still be inadequate to protect public health to the degree society desires. There are substantial concerns about a number of wastewater constituents that are not addressed by current regulations—antibiotics, endocrine disruptors, household chemicals (e.g., in cleaners and personal care products), specific carcinogens (e.g., nitrosamines), viruses, and others (Huang et al. 2001; McGovern and McDonald 2003). Many of these emerging constituents of concern are not substantially removed by most current wastewater technologies. The increasing number of immuno-compromised individuals in our society also raises questions about the adequacy of current standards. How these concerns are addressed by regulators will in the future be very important to technology requirements, and their costs, for all wastewater systems.

The tools of risk assessment (Jones et al. 2001; Jones et al. 2004) can be brought to bear on many of these issues, though in the absence of good information and scientific understanding of some of these issues, all tools have limited utility. Given ever-present concerns—are our regulations good enough to ensure public health?—substantial efforts continue in the research community to understand the fate and transport of pathogens in the environment (Cliver 2001), the fate and transport of nitrogen (Gold and Sims 2001), and the fate and transport of emerging constituents of concern (Huang et al. 2001; McGovern and McDonald

2003). The results of such studies will inform risk assessments prepared by competent specialists as well as ongoing regulatory change.

In terms of the economics of public health issues related to wastewater systems, a number of useful references are available (Conservation Ontario 2001; U.S. Environmental Protection Agency 1995).

9.8 Worker and public safety

Decentralization consideration: *Occupational health and safety risks and hazards to the public vary by technology and system scale and should be considered when system choices are made.*

According to Patricia Miller (2001) common hazards for inspectors, septic tank maintenance personnel (and sometimes the public) include:

- *Pathogens.* Inspectors and maintenance workers who come in contact with wastewater are susceptible to diseases caused by pathogens that may be in the wastewater.
- *Lifting/carrying injuries.* Lifting septic tank lids, invasive maneuvers and lifting, boring into soil, and boring into a drainfield trench, can cause back injuries or other injuries.
- *Hazardous Gases*. Inspectors and maintenance workers may come in contact with hazardous gases from older or improperly vented septic tanks that can cause explosions, suffocation, and/or respiratory paralysis.
- *Confined Space Hazards.* Workers and inspectors required to enter septic tanks, especially deeply excavated septic tanks, can encounter collapses, lack or air, and/or hazardous gases (e.g. hydrogen sulfide). Proper safety and rescue procedures for confined spaces should be practiced.
- *Electrical Hazards.* Electrical equipment may be used for the wastewater system, placing inspectors and workers at risk of electrical shock.
- *Open Excavations and Boreholes.* Excavation for inspections or maintenance present risks of collapse or burial. In addition, old, deteriorated septic tanks pose collapse risks.
- *Risers and Access Openings.* Open risers and access openings can trap or drown young children playing in the area.
- *Insect and Snake Bites.* Underbrush and/or dark quiet areas associated with the onsite wastewater system may be inhabited by dangerous insects, spiders, and snakes potentially causing harm to inspectors or maintenance personnel working on the system.
- *Poisonous Vegetation.* Inspectors or maintenance workers may come in contact with poisonous vegetation while working on onsite wastewater systems.
- *Dogs*. Inspectors and maintenance workers that deal with household wastewater systems may come in contact with dogs who could be hazardous if they believe their home, yard or family is threatened.

Many of these hazards also pertain to centralized wastewater systems. The Water Environment Federation 2002 bookstore catalog has six publications on safety and health risks at wastewater treatment plants. Sewer systems require specific safety procedures due to confined spaces (Pettit and Linn 1987).

Sewer trench collapses are an especially significant hazard with centralized wastewater systems. A Purdue University research team analyzed 52 Fatality Assessment and Control Evaluation reports associated with trenching and excavation operations from 1985 to 2000 (Stiles 2003). The group found that sewer systems (35 percent) and water supply systems (15 percent) have the highest trench-related fatalities. As examples, they recount that in April 1993 an independent contractor, 34 years old, died from traumatic head and neck injuries from a sewer line excavation cave-in in Alaska. In 1999 a 17-year-old laborer died and his coworker was injured from a collapsed trench wall that struck and partially buried them with soil. To help prevent additional trenching fatalities and injuries trench-box devices are commonly used, and recently computerized robotics have been developed to alleviate the need for workers to enter trenches for pipe laying operations.

Fatalities have occurred with decentralized systems as well. For instance, in Michigan a two-year old child fell into a septic tank with a lightweight, unsecured riser cover and drowned (Miller 2001). It is difficult to generalize about the relative safety and occupational health risks associated with wastewater systems, given the variability of system characteristics and resulting hazards. For example, do septic system maintenance contractors have a higher illness rate per hour worked than workers at centralized wastewater treatment plants? To our knowledge, this question has not been researched.

9.9 Fairness and equity issues

Decentralization benefit: *Smaller systems are less likely to raise questions over the distribution of their costs and benefits.*

The costs and benefits of centralized and decentralized systems fall on citizens in very different ways, and can raise a host of fairness and equity issues. In general, the smaller the system, the more likely it is that costs and benefits accrue to those generating a need or making an investment. Conversely, the larger the system, the more the chance that costs and benefits will be distributed out of proportion to need or investment. For instance:

- *Issues in distribution across time.* Decentralized treatment is constructed on a unit-by-unit basis as properties are built. Centralized treatment plants and collection systems are built with excess capacity for future expansion. Depending on the financing mechanism, this may produce a subsidy by present ratepayers to those who move in later on. This is not uncommon in large infrastructure projects, however, and may be readily accepted in communities where growth is being encouraged. In other communities, where an influx of new residents is resisted, imposing extra costs on present residents is likely to be contentious.

  In some places, where strict requirements on new onsite treatment systems are necessary due to the loading produced by inadequate or failing existing systems, new growth may, in effect, subsidize previous development.

- *Issues in distribution across space.* Costs to provide wastewater services are rarely equal between different portions of a service area. Centralization socializes costs across a service area. The larger the service area, the greater the likely differentials and the potential for equity issues due to low-cost areas supporting high-cost areas.

  Also, sometimes the rich receive publicly funded infrastructure when poorer citizens do not, as when sewers are constructed to serve lakeside properties that only the affluent can afford, while other nearby, less-affluent areas go unsewered. “Environmental justice” issues should be evaluated when facility siting and funding decisions are made.

- *Issues in distribution relative to use.* Onsite systems must be built for the particular influents associated with the attached home or facility. In cluster and sewered systems, some users—e.g., restaurants, schools, and industry—may load the system out of proportion to other users such as residences, raising questions of whether pre-treatment should be required, or differential pricing instituted.

Besides questions over the fairness of who pays and who benefits, questions will arise as to whether a subsidy is justified or not. For some communities, subsidizing wastewater management for sensitive resource areas, or for important employers, may be reasonable.

Also, the absolute amount of and trend in shared costs may affect the debate. This can occur, for instance, in the sharing of fixed or step-function costs associated with growth. When the choice of treatment scale affects the density of development, it may thereby affect the number of residents available to pay for roads, schools, and other infrastructure. This may lower costs per resident, or increase them if a threshold is reached where larger roads, schools, and so on are required. Some residents may be unwilling to pay for a system that will result in costs they must share, but benefits that fall (in perception or reality) mainly to developers, businesses, and others.

Rate structures can potentially account for some cost differentials across time, space, and use, but often do not or cannot. The larger the differential, the harder it is to develop workable, equitable rate structures. For instance, Richard Peiser has shown that because of the carrying costs incurred while demand grows into excess capacity for larger facilities, economies of scale for large facilities must be significant or impact fees cannot be structured in a manner that provides equity over time (Peiser 1988).

In short, decentralized systems of appropriate scale tend to deliver the costs and the benefits of a system to the same people at the same time, thus tending to reduce both actual and perceived inequity. Since perceived inequity is often at the root of conflict, decentralized systems can be less costly by being less contentious.

Some examples of equity issues in specific wastewater systems follow.

Florida. Brad Smith (2001) reports on concerns in this state that urban centers provide hidden subsidies for suburban growth and sprawl. For instance, a Florida State University study found that the actual cost of a sewer hookup in Tallahassee was $4,447 for inner-city neighborhoods near the treatment plant, while connections in upscale areas at the edge of town cost $11,433. Yet all households paid the same for sewer connections, roughly $6,000. That the inner-city neighborhoods are mostly black raises an additional issue of class and racial equity.

Paradise, California. Interests in the commercial district of Paradise opposed an initial sewer proposal because both design and construction costs of the centralized system were to be borne exclusively by them. Some businesses felt the costs would make them less competitive with businesses in the nearby city of Chico. Businesses created much of the necessity for the central sewer, yet felt that the whole town should share the costs of the treatment system, as residents would benefit from the increased tax base afforded by improved commercial activity and from septage management at the proposed treatment plant.

For this and other reasons, the town council chose to assess all properties in Paradise for the sewer design work, along with development of an onsite wastewater management zone for residential areas. This irritated many people outside the commercial district. Many local residents considered the plan, focused as it was on sewering the commercial district, a gift to developers. Sewering would benefit business owners. Many people didn't see other benefits, both subtle and general: an increased tax base, more money in the general fund, improved water quality, more shopping opportunities.

Further, sunk costs and fixed incomes raised equity issues. Some businesses that had already invested in pretreatment systems questioned why public funds should be spent on a collective system, instead of other businesses paying for their own systems too. Also, because a large number of Paradise residents are retired and living on fixed incomes, the additional costs of sewer design or sewer implementation raised concerns about affordability and fairness. Ultimately, citizens revolted. They recalled four out of five members of the town council that established the assessment, and voted down the sewer proposal (Pinkham et al. 2004).

Washington Island, Wisconsin. Long-time year-round residents of Washington Island built on land in the island interior, which has adequate topsoil for soil-absorption systems. One resident described the original island people as "land rich and money poor." Newer residents predominately built upon small lakefront lots that were unable to biologically assimilate sewage, and thus utilized holding tanks. During the wastewater facility planning process, there was a sentiment among old-timers that building on property unable to assimilate wastewater was reckless. It challenged the notion of individual responsibility that has been an underlying ethic of life on Washington Island since its settlement.

The shoreline lots were also much more expensive, and many of these property owners were seasonal visitors or lodging operators. This disparity between new, higher-income, seasonal residents and long-term, lower income residents created an interesting dynamic when the community decided on a wastewater treatment system. Owners of both failing conventional septic systems and owners of holding tanks created the need for wastewater management. But owners of holding tanks stood to gain much more from the construction of a centralized treatment solution, as fewer options were available to them given their poor soil and small lot sizes. At the same time, seasonal residents also questioned "why should we pay all this money for something we only use six weeks per year?"

Some participants in the planning process recalled that an "us and them" mentality began to emerge between full time and seasonal residents. The community's citizen Wastewater Committee worked hard to head this off. To facilitate discussion about equity issues, the Wastewater Committee introduced an analogy to the automobile catalytic converter, which is used to remove pollutants from auto emissions. The argument went like this: "Every car needs a catalytic converter. If you have five cars in your driveway, should I have to pay for your catalytic converters, or do you have to buy five catalytic converters?" The ensuing discussions led the town down the path of individual responsibility for wastewater treatment needs. Ultimately a centralized treatment proposal was shelved and a decentralized approach chosen instead (Pinkham et al. 2004).

Decentralization benefit: *Maintaining decentralized systems as permanent solutions avoids the "double payment" problem sewers can create.*

Often, when sewers are extended into areas served by existing onsite systems, property owners pay twice for wastewater service. Once for the original onsite system, then again for a sewer connection, which is usually mandated. This can raise questions of fairness regarding which areas (and who) gets sewers, and when.

Consider the case of Charlotte County, Florida (Pinkham et al. 2004). In 1990, a development company that had platted many thousands of lots in Charlotte County went bankrupt. Many property owners had bought lots with the expectation that they would be provided sewer service. When Charlotte County acquired the developer's utility company, it may have acquired an obligation to provide sewer service to all lots platted by the developer. The issue became largely theoretical when the cost of the proposed sewer system became known. Most lot owners did not want sewers because of the cost.

Residents who had already built had a different problem: why should they have to pay for a sewer when they already had a wastewater system—a septic system—that, most believed, worked just fine? Many believed septic system pollution had not been satisfactorily documented. Perhaps this question would not have been posed with so much emotional force and resistance behind it if the cost of the proposed sewer system had been lower. The main concerns were affordability for retirees and the perceived unfairness of requiring payment for a second wastewater system. These issues were all the more acute because of the low value of most houses in Charlotte County. Residents believed that a $50,000–$60,000 house would take many years to appreciate enough to pay off an investment in sewer service that approached $10,000. The idea of absorbing the cost with a second mortgage had little appeal for many residents, especially older ones.

Several years after defeat of the massive sewering proposal, in its 1997 comprehensive plan, the county developed a variety of policies and programs designed to encourage growth in some areas and discourage it in others. Providing sewer service to some areas—dubbed the "mini-expansion" program—was a key component. To ensure financial viability of any sewering, and to be consistent with state law, the county adopted a policy mandating that homes connect within 365 days of a sewer becoming available. Some county residents with onsite systems protested this policy vigorously. A legal challenge to the policy was filed, on the grounds that mandatory connection was unconstitutional. The challenge failed. To soften the affordability and "paying twice" fairness issue during the mini-expansion program, the county developed several programs. Residents could receive a 10 percent discount on the connection fee by fully paying the fee up-front. Or they could pay the full fee over seven years at 8 percent interest. Residents meeting certain low-income requirements could receive financial assistance from state funds administered by the county housing authority.

9.9.1 Relative status of operators

Decentralization benefit: *Centralization increases the expertise required of system managers and operators, and therefore the compensation required to retain them, perhaps to a point that generates ill will in some small communities.*

The salary required to hire a treatment plant operator may exceed that of other key officials, such as a mayor or town administrator, in a small community (Metcalf & Eddy Inc. et al. 1991, p. 1019). This can create a social equity and political problems.

Labor requirements for system O&M are should be estimated by consulting engineers or others in the preliminary design phase. Such studies often indicate assumed salaries or hourly rates for operators, which can be compared to those of other local officials. These considerations can also be addressed in the conceptual planning phase where they are deemed of importance. Equity implications must be addressed by qualitative consideration, perhaps as part of a matrix prioritizing non-monetary system choice criteria, or via a multi-objective approach.

9.10 Stakeholder relationships and trust

Community wastewater decision making processes are strongly affected by the types, timing, and methods of presentation of key information, as well as the structure of the decision processes. The form and content of community debate about wastewater projects can significantly affect the image of key stakeholders in the eyes of other players and the public at large.

Decentralization benefit: *Decentralizing infrastructure units tends to reduce the political and economic "stakes" involved in a wastewater facility decision. This can reduce community conflict and its associated costs.*

A facility planning process in Paradise, California (Pinkham et al. 2004) reveals how centralization of wastewater services can raise and intensify issues of trust within communities. A centralized collection system and treatment facility was proposed in the early 1990s for the mainly commercial portions of this town of 25,000. The costs of planning and designing the system (let alone construction)—$4 million including bond interest—became a bone of contention because the allocation of assessments to pay these costs was perceived as inequitable: the assessment was made on all properties in town (planning also included development of an onsite management zone), and it was based on parcel size and did not account for the development potential of a parcel. The choice of an open-ended assessment mechanism led many residents outside the sewer district to believe they would be asked to pay for the estimated $20 million construction cost as well. Many residents perceived the proposed system as pro-business. Many saw it as pro-growth and contrary to their vision of the town's future. As planning proceeded, expansion of the sewer service area to properties of prominent individuals with development aspirations led to charges of cronyism on the part of Town Board members. And to many citizens, it appeared town officials were "on a track" and unwilling to listen to the desires and requests of the public. These concerns reached the point that Paradise voters in 1992 recalled four town council members and voted down the proposed centralized system. The divisive politics of that time lingered for years, making other major initiatives in the community very difficult because of the low level of trust citizens held for elected officials and each other.

Decentralization benefit: *By breaking borrowing needs into smaller amounts that occur periodically as a community grows, decentralized systems can help avoid mistrust and rate shock brought on by large borrowing for capacity that will not be fully used for years.*

This benefit relates to those described in §8.5 on debt load. It occurs for two interrelated reasons. First, the increments of borrowing can themselves be smaller, both in amount and in proportion to a community's ability to pay. Second, as the community grows, so too does its financial capacity. The net result is that smaller amounts are borrowed when they are most affordable. If O&M costs are reasonable and the utility or community's financial condition is well-managed, these aspects of decentralized project borrowing should allow for rates to be kept steady or increased in small steps over time. The political benefits of avoiding rate shock should not be underestimated. And the economic value is real, as becomes apparent when rate shock occurs.

Decentralization benefit: *Smaller systems lend themselves to local decisions, enhancing public comprehension and legitimacy.*

Technologies that are relatively easy to understand, due to their technical characteristics and/or their human scale, can enhance both the feeling and the reality of political choice at a sufficiently local level to provide reasonable accountability and public support. For every step up the centralization scale, some level of personal or community autonomy and influence may be lost, and assuring legitimacy becomes more important and difficult. Moving from onsite to cluster systems requires cooperation with neighbors; from cluster to centralized systems requires participation in local government; from centralized to regionalized systems requires arrangements and decisions that are made far from the places most users live, and may be highly political. Decision making around smaller systems, on the other hand, tends to fit better with stakeholder engagement at a community and local scale, allows for flexibility in system design, and provides a sense that the enterprise is of a comprehensible scale more likely to prove politically accountable. These attributes can reduce the potential for conflict, and hence moderate planning costs, financial risk, and delays in approvals. However, it should be noted that management of decentralized systems, which is essential to effective decentralized treatment, requires a level of consensus across a larger area than that served by the individual treatment units.

10 Onsite and neighborhood impacts

This chapter addresses a range of system choice implications that are experienced by community members mainly at the scale of individual properties or neighborhoods. Depending on the particular wastewater system and the size of the community, some of these issues do “scale-up” to the community level. For instance, odor problems and construction impacts can affect an entire community. But in most cases the direct effects are localized.[26]

Onsite and neighborhood impacts may be both tangible and intangible in economic terms. Tangible impacts have direct monetary implications. Examples include:

- Restoration costs for disturbance to streets, lawns, and other landscape features for installation or repair of collection or treatment systems;
- Costs for relocating utilities to install collection or treatment systems;
- Increased value of property if a more centralized wastewater system allows higher density development;
- Loss of property value if a wastewater system component precludes other desired uses of a portion of a property.

Intangible impacts have less direct monetary implications, though they often do affect property value. For example:

- Inconvenience of restrictions on septic system use;
- Hassle of operating and maintaining a wastewater system and dealing with permits and other regulations;
- Aesthetic issues (odor, noise, visual impacts), which in some cases (and often in combination with health and environmental concerns) may raise a wastewater system to the status of “Locally Unwanted Land Use,” or “LULU.”

The following pages discuss these and other issues in more detail. In terms of valuation, a variety of techniques may be appropriate. In general, two approaches are widely useful for valuing onsite and neighborhood scale impacts. **Cost estimation** tools and **engineering economics** can provide either direct costs (such as utility relocation), or place a value on a system option that avoids a negative impact by calculating the costs of mitigation measures (such as odor control equipment) that would be necessary for another option. The other generally relevant approach is based on property value appraisal and related **hedonic pricing** techniques. These techniques are useful because many of the impacts discussed below, both tangible and intangible, affect property value in some way. However, readers are warned that hedonic pricing can require significant resources and economic expertise, and do not always yield clear results. Indeed, property value comprises many things, and it is often analytically difficult to separate, for instance, the affects of odor, noise, and visual impact from each other, or from other value factors. Nonetheless, those aesthetic issues, and other issues described below, are not necessarily co-existent, and so are discussed separately.

[26] Many issues in this chapter can also “scale up” by affecting attitudes regarding community control of nuisances, equity of system costs, trust of decision makers, and other political issues (Zeiss and Atwater 1991). Those issues are dealt with in §9, on issues at the community and watershed level.

10.1 Convenience, intrusion, and other intangibles

Decentralization cost: *While centralized wastewater systems are essentially out of sight and mind for most property owners (excepting payment of sewer bills), onsite and cluster systems require greater awareness and participation, with attendant non-monetary costs.*

Onsite and cluster systems often require property owners to accept non-monetary costs that can be significant. Nelson et al. (2000, ch. 5) cite various studies (Dillman 1999; Herring 1996; Ingram et al. 1994; Jantrania et al. 1998; Nelson 1999; Nelson et al. 2000; Otis et al. 1981; Piluk 1998; Sandison 1997; Uhren 1991; Washington State Department of Health and Puget Sound Water Quality Authority 1996; Wayland Wastewater Management Committee 1995) that indicate the following factors are critical to the acceptability of onsite and cluster systems and management to homeowners:

- difficulty of and time spent on maintenance;
- inconveniences of limitations on garbage disposals, washing machines, etc.;
- burdens of rules and regulations, and opposition to public bureaucracies;
- private property rights and resistance to intrusion of outsiders into backyards;
- aesthetic concerns about mounds, risers, etc.;
- equity issues, or unwillingness to pay for someone else's system; and
- voluntary risk vs. involuntary risk.

Many of these issues are not necessarily inherent problems with decentralized systems, but result from consumer and institutional experiences and biases that may be successfully addressed in particular cases by appropriate choice of technologies and management systems, and may change in a general sense over time as better technologies and institutions become widespread. Facility planning should review these issues to determine their significance, as explained below:

Maintenance activities. Onsite systems require maintenance, which a property owner must perform or arrange for. Where owners are aware of maintenance needs (too often they are not), those needs are often considered difficult and time consuming, especially for advanced systems. Consumers like the simplicity of septic systems, and when higher performance is required, tend to choose sewers over the option of advanced onsite systems and professional management, even when sewers are more expensive (Nelson et al. 2000, ch. 5).

Limitations on use. Nelson et al. (2000, p. 5-7) summarize the inconveniences of onsite systems:

> Onsite systems may limit certain lifestyle choices of the homeowner, particularly in contrast to central sewers. Homeowners are typically instructed to avoid flooding the system by doing too much laundry on any given day, not to drive a car or other equipment over the leachfield, not to use a garbage disposal or put bleaches, oil or grease down the drain, etc. Advanced systems may have more restrictions than conventional systems. If the power goes out, minimal water should be used, since pumps, ATUs [Aerobic Treatment Units], etc. will be non-operational. Hooking up to a sewer can free up a homeowner to add bedrooms or install a dishwasher and washing machine. As Sharon Nelson, a citizen activist from Vashon Island, Washington recently put it, "if onsite systems become too difficult to maintain and require too many lifestyle changes, there is no future for onsite."

Some of these issues must be accepted, at some loss in value relative to systems that do not require a particular lifestyle compromise.[27] Others can be addressed in system design, but often at a cost in larger

[27] It should be remembered that quality of lifestyle is a very subjective and relative concept. In many cases, particularly where options are limited, "inconvenience" is accepted as insubstantial, or as a trade-off for other lifestyle gains, and the loss is minimal or zero.

systems or additional technology. Hydraulic loads can be accommodated in system sizing. Garbage disposals are an issue because they increase the amount of BOD, suspended solids, and grease in wastewater. These constituents can be handled with larger septic tanks, and sometimes also require increased size of the wastewater soil absorption system (WSAS) (U.S. Environmental Protection Agency 2002d, pp. SIFS-3–SIFS-5). For some issues, the need for compromises or design changes is unclear. For instance, there is some disagreement in the wastewater field as to the impacts of water softeners on onsite systems (National Small Flows Clearinghouse 2001).

Regulatory burdens. In a general but important sense, central sewerage relieves users from the responsibility of ownership (Otis 1998). These responsibilities include the just-noted issues of maintenance and care in use, and meeting the relevant rules and regulations of public health departments, building departments, management zones, and other entities. Owners of onsite systems are subject to a variety of regulations addressing both new and existing systems (National Small Flows Clearinghouse 1998). Requirements for new systems may include site evaluations, setback requirements, design specifications, permits, construction inspections, and more. While a developer, contractor, or engineer may take care of many of the details, these requirements do place a certain burden on the homeowner. For an existing system, permits may have to be renewed periodically, inspections arranged, operation and maintenance requirements satisfied, system changes approved, systems evaluated upon property transfer, etc. Regulatory burdens typically are greater for advanced onsite systems compared to conventional septic systems.

For centralized systems, regulations governing on-lot portions (e.g. sewer laterals) also exist, but they are typically "invisible" to homeowners except when laterals fail and must be replaced. The responsibilities and regulatory burdens felt by users of cluster systems tend toward the lower burdens of centralized systems, but depend on the system configuration and the legal and operational structures governing the sharing of responsibility between connected properties.

Developing management systems that make decentralized systems "feel" more like traditional, utility-managed centralized wastewater systems, possibly through public ownership of onsite facilities, is a key to increasing their acceptance, according to some experts (Otis 1998). Others question the political feasibility of accomplishing this given homeowner desires for control of their private property (Nelson et al. 2000 p. 5-14). Increased public oversight and regulation through management schemes is often resisted as unnecessary and unwanted bureaucracy—more so for situations where management is overlaid on existing development than in the case of new development where management is clearly part of the package ones buys into (Nelson et al. 2000, ch. 5). The costs and benefits of management are further discussed in §13.

Private property and intrusiveness. A related issue is that management schemes that require public inspection or maintenance of onsite systems are often resented as intrusive upon private property. Government officials in the backyard are not welcomed. These concerns may be mitigated by management schemes that allow choice; for instance, in which property owners contract with private companies to provide necessary services, just as an owner on a central system would be able to choose who they wish to provide services to a sewer lateral (Nelson et al. 2000, ch. 5)

Aesthetics. Aesthetic issues are discussed later in this chapter.

Equity issues. There is some evidence that consumers resist the cluster system concept because shared responsibility can mean paying for another owner's needs and for failures caused by others' mis-use or sabotage of a system (Nelson et al. 2000, ch. 5). This issue is most pronounced for small clusters of only a few users. Equity issues may also arise over whose land is used for the treatment unit and dispersal field.

Equity can be an issue across the full range of scale. While concern for failures caused by others is probably not an issue with centralized systems, sharing of costs and responsibility clearly is, as shown by case studies of facility planning processes in Paradise, California and Washington Island, Wisconsin

(Pinkham et al. 2004). In general, it appears people often prefer smaller systems over larger systems because the costs are perceived as being more directly placed on those most responsible for them. This topic is discussed in detail in §9.9.

Voluntary vs. involuntary risk. Many of the issues discussed above relate to preferences regarding the assumption of risk. Generally people tolerate higher voluntary risks, or those perceived to be under their own control. This helps explain consumer resistance to management regimes they feel are imposed on them, and reluctance to participate in cluster systems where performance and management is beyond their control. Systems that impose involuntary risk and reduce control can be considered to produce economic welfare losses. One must be very careful, however, assigning such losses for different scales of systems.

In summary:

- Consumers often see advanced systems as having higher non-monetary costs than simpler systems. So-called "flush and forget" sewers are preferred over systems requiring more consumer responsibility.
- Outside management may create non-monetary costs.
- Clustering is often seen as costly in terms of equity and loss of control. These same concerns may or may not arise at higher levels of centralization.
- The level of non-monetary costs at any particular system scale would appear to depend greatly on technology choice and the structure of wastewater management institutions. Therefore, comparisons must be made specifically and carefully.

Because of the highly complicated, interrelated, and "fuzzy" nature of the issues described above, qualitative methods are the most feasible approach to their valuation, and may be most appropriate. Experts can attempt preliminary judgments and rankings, but ultimately public participation is essential. Results of evaluations will be highly location specific.

Surveys can be a useful tool. For instance, Nelson et al. report on a manufacturer's survey (Infiltrator Systems Inc. 1999) that quantified attitudes in one community:

> Infiltrator Systems, Inc. surveyed 95 residents, age 55 to 69, with homes ranging in value from $250-300,000 in Plymouth. Ninety percent responded that homes on a sewer have higher value than homes on septic systems, and the average perceived differential was $9,244.88 This study also confirmed the disinclination of homeowners to support professional inspection and maintenance requirements. Sixty-one percent of respondents preferred homeowner responsibility for installation, maintenance, and repairs of the septic system, compared to 34 percent in favor of a professionally managed and guaranteed or insured septic system with a standard monthly fee (Nelson et al. 2000, p. 5-2).

Care must be taken in administering and using any such surveys, and in public participation on these issues in the facility planning process. It is important that such work be based on an adequately informed public, rather than simply taking existing perceptions as a given.

Hedonic pricing may also be a useful approach. For instance, a hedonic valuation approach could address a question such as: How much lower are housing prices, all else being equal, for homes with frequent inspections and limitations on quality of life compared to homes with no outside maintenance requirements? Such an analysis would require that enough homes with the relevant quality-of-life characteristics are available within the community under study or similar communities within the same geographic region. Hedonic pricing can be resource-intensive and does not always yield clear results. A more feasible approach might be to compare values of equivalent homes with different scale wastewater systems. However, this analysis would not isolate non-monetary costs. Differential operating costs, replacement costs, and other factors would be incorporated in the values to the extant they are perceived within the market and have been capitalized into home values.

A more promising valuation approach might be the **defensive expenditures** method; that is, to determine the marginal costs of design features to address issues of concern; e.g., larger sizing to reduce inconvenience of limitations on water use. This would give an indication of the value of system choices that avoid the issue for which the costs are estimated, compared to a system that raises the issue and is not designed to overcome it.

10.2 "LULUs"—Locally Unwanted Land Uses

Decentralization benefit: *Centralization intensifies undesirable system characteristics that induce public resistance and loss of value for neighboring properties.*

People dislike being near wastewater treatment plants. Larger plants especially tend to concentrate odors, noise, visual impacts, and other nuisances. Utilities wishing to avoid political backlash from siting of wastewater facilities sometimes go to great lengths to address concerns of nearby residents and property owners. For instance, Phoenix is building several distributed (but still substantial) wastewater reclamation plants throughout the city, so neighborhood perception is a key concern. The first plant built in this system incorporates a variety of strategies to reduce impact: greater-than-usual setbacks for process units, low-profile domes, placement of many structures below grade, low-noise equipment, several odor scrubbing strategies, extensive screening with walls and landscaping, etc.—all designed to make the plant as "invisible" as possible (Gritzuk et al. 2002).

The dynamics of "locally unwanted land uses," or "LULUs," trace most obviously to aesthetic impacts. But a broader dimension exists as well, of deeper political issues such as equity, loss of neighborhood and community image, feelings of loss of control and influence on public decisions, and fear of health impacts (Zeiss and Atwater 1991). These issues are discussed in more detail in §9. Particular aesthetic issues, which may be separable from each other and from the larger issues just mentioned, are discussed in following sections. This section notes the overall impact of wastewater facilities on neighbors. The influence of system scale on the LULU phenomenon can be summarized as follows:

- Onsite systems may be considered LULUs by neighboring property owners. Typically this occurs when system failures produce aesthetic insults or public health concerns. It may occur if poor system choice, design, or construction (e.g. leaving inspection risers too high) produces unnecessary aesthetic impacts.
- Cluster systems may be considered LULUs by neighboring property owners. This may have as much to do with issues of public process and control and irrational fear of proximity as real aesthetic or health impacts. Many stories exist of decentralized treatment units being placed in aesthetically pleasing buildings and still being resented.
- Centralized treatment systems are clearly viewed as LULUs by the general public.

At the cluster and centralized scale, an important dimension of the LULU phenomenon is the relative impact of "multiple LULUs" potentially created by distributed systems versus "concentrated LULUs" of larger plants. Distribution may reduce physical impacts on adjacent properties. This may increase general dissatisfaction, or may appear as more equitable. Typically, reaction is more intense the larger the plant. Much depends on the actual location(s) and the nature of the decision making process.

Hedonic pricing techniques might be appropriate for determining the economic losses experienced by neighbors of LULUs. Such an analysis would address the relative value of properties adjacent to wastewater facilities and similar properties at a distance. A **defensive expenditures** approach might be more practical and could yield clearer results. For instance, in the Phoenix example above, this method would use the additional costs, versus conventional design, of the measures implemented to reduce impacts on the surrounding neighborhood to help estimate the economic costs of this approach to infrastructure versus some other approach.

10.3 Aesthetics: Visual impacts

Decentralization consideration: *Visual impacts of wastewater systems on sites and neighborhoods may occur with any scale system.*

Many features of wastewater system may negatively impact the visual attractiveness of sites where a system is located, and sometimes the surrounding area as well. Some of these features are shown in Table 10-1.

Table 10-1: Visual Impacts of Wastewater Systems

Onsite Systems	Cluster Systems	Central & Regional Systems
Risers Manhole covers Mounds Electrical boxes Alarm lights Blower boxes Filter media covers	Risers Manhole covers Buildings housing treatment systems Electrical boxes Covers or exposed portions of treatment units or treatment media	Treatment works Industrial buildings Parked trucks/equipment Parking lots Open wastewater tanks and ponds Biosolids handling facilities

In general, the following tendencies for visual impact occur:

- Decentralization disperses impacts, creating more impacted sites, but typically “smaller” impacts that may be less noticeable onsite and/or from a distance.
- Centralization concentrates impacts, resulting in fewer impacted sites, but typically more noticeable ones.

The actual impact depends strongly on the particular technology employed. For instance, among decentralized systems, conventional onsite systems may show risers, but little else, while mound systems alter the landscape, and pretreatment units may require equipment (e.g. blowers) that are partially or wholly positioned above ground. Location also affects impact. For instance, a centralized facility in an industrial district will have less of a visual impact than one located in or adjacent to public open space. Also, the perceived impact may depend on whether the system is a new installation in a new development, or a retrofit to an existing development, which is likely to produce stronger aesthetics concerns because of the change to an already familiar landscape.

Visual impacts may be mitigated in a variety of ways:

- Choosing a treatment scale or treatment technology with reduced visual impact;
- Siting and design measures (e.g. deeper placement) that minimize visual impact;
- Landscaping and construction of screening devices, buildings, and other features to hide objectionable parts of a system.

Visual impacts can be most easily valued via a qualitative approach. If necessary, the economic value of a visual impact can also be quantified in a number of ways, both within and across system scale:

- Determining the marginal cost, through standard cost estimating procedures, of mitigation measures to avoid a visual impact. This is known as the **defensive expenditures** method.
- **Hedonic pricing** to determine the market price difference of similar properties with and without the visual impact of concern. Separating out other factors to obtain true comparables may be difficult.

- **Contingent valuation**—surveying property owners, neighbors, and potentially passersby to determine their willingness to pay to eliminate a visual impact.

10.4 Aesthetics: Odor

Decentralization benefit: *Odor control is typically less of a concern with smaller systems.*

By concentrating wastewater in larger quantities, more centralized systems create a larger potential odor source, including both wastewater treatment units and sludge handling facilities. Odor is a key reason WWTPs are often considered LULUs—"locally unwanted land uses." Besides impacting immediately adjacent properties and neighborhoods, concentrated gases from treatment facilities can travel great distances without substantial dissipation, a phenomenon known as "puff movement" (Metcalf & Eddy Inc. et al. 2003 p. 1654). Collection systems also generate odors, which can be released at cleanouts, manholes and other access points, air release valves, and vents at houses.

Mitigation of odors is a major concern in the planning, design, and operation of conventional sewage treatment plants. A variety of technologies may be incorporated to control odors (Metcalf & Eddy Inc. et al. 2003, pp. 1650-1675).

Decentralized systems can also suffer from odor problems, chiefly from "anaerobic decomposition of organic material or reduction of sulfates to hydrogen sulfide" (Crites and Tchobanoglous 1998, p. 331). Onsite systems such as septic tanks are generally well-enough contained that odor escape is minimized (Crites and Tchobanoglous 1998, p. 332). Odor problems with onsite and small cluster systems are typically transient, resulting from system startup, specific infrequent events such as pumping of a septic tank, or from system failure. Larger decentralized treatment systems can begin to have problems similar to centralized facilities and may require similar mitigation measures. Small collection systems can generate odors on an ongoing basis, but simple measures such as soil filters or activated carbon cartridges on air release valves are often sufficient to deal with problems.

The economic value of a system choice that avoids or reduces odor problems (or the cost of one that does not) is typically not quantified, but can be and often is addressed qualitatively within a facility planning process. Economic quantification of this value can be accomplished in a number of ways, both within and across system scale:

- Determining the marginal cost, through standard cost estimating procedures, of mitigation measures to avoid an odor impact (the **defensive expenditures** method). Measures that add to cost without also improving the water quality treatment performance of a treatment plant can properly be noted as odor control costs. Often such measures are included in a facility design. If odor control is not included, but is still considered a problem, the cost of non-incorporated control measures can be considered an economic benefit of systems that do not present an odor control problem.
- **Hedonic pricing** to determine the market price difference of similar properties with and without odor problems from a wastewater system. Separating out other factors to obtain true comparables may be difficult.
- **Contingent valuation**, which involves surveying property owners, neighbors, and potentially passersby to determine their willingness to pay to eliminate an odor impact.

10.5 Aesthetics: Noise

Decentralization consideration: *Both centralized and decentralized systems can be noisy or quiet, depending on the technology chosen.*

Many decentralized systems are entirely passive (gravity-drained septic systems) or have very small, usually buried pumps (recirculating sand filters) that produce little noise. Aerobic treatment units, on the other hand, usually have an above-ground blower motor which can generate noticeable noise, though the impact will depend on distance from the house. ATUs and some other systems may have alarms that sound when a pump failure or other malfunction occurs, potentially disturbing neighbors. Some centralized plants may have large pumps, blowers, and other devices that create noises heard at some distance from the plant. Enclosures and other measures can mitigate these noises. Some centralized systems, such as lagoons, produce little noise. Centralized facilities are likely to have more frequent truck traffic, which can create unwanted noise at the neighborhood scale.

The methods for valuation of odor impacts discussed above can also be applied to valuation of noise impacts.

10.6 Other effects on property values

Besides the property value impacts of wastewater system aesthetics described above, the choice of a wastewater system can affect property values in additional ways. These factors are discussed below. All the costs, benefits, and considerations in following sub-sections are appropriately valued using either conventional real estate valuation (appraisal) techniques or **hedonic pricing**.

10.6.1 Open space

Decentralization benefit: *Decentralization allows for preservation of open space and its attendant values without the costs of unnecessary infrastructure.*

Where zoning and wastewater regulations allow, clustering of development at higher density on a portion of a property serves to preserve open space. Large-lot zoning may also preserve open space.[28] WSAS fields themselves may serve as open space. Property adjacent to open space is often more valuable than property that is not.

The value of such open space depends on context. In urbanizing areas, proximity to open space frequently increases property value. In rural locations where open space is abundant, the value of open space generated by cluster development or represented specifically by a cluster WSAS, wetland treatment system, or other land intensive system is reduced (Kofner 2001).

Open space can of course occur in communities served by centralized systems. However, as discussed in §11.2.2, open space increases the length per connection for collection systems, often creating diseconomies of scale in capital investments as system size increases.

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[28] While large-lot zoning for onsite systems is often promoted as a way to preserve open space and reduce development densities, this approach may have undesirable consequences for historic landscapes and desired land use patterns, and reduce the value of existing lots that do not meet the minimum requirements. Also, the quality of the open space may vary substantially. In Lake Elmo, Minnesota, prior to development of an open space ordinance enabled by cluster wastewater systems, zoning that required 2.5 acre or larger lots frequently resulted in “Prairie Palaces”—monster homes with acres of mowed bluegrass and two “lollipop” trees at the driveway end—to the dismay of local officials who had hoped large lots served by septics would maintain a semi-agricultural and diverse natural prairie atmosphere in town.

10.6.2 Density and property value

Decentralization cost: *The greater the degree of decentralization, the greater the limit on development density. Where higher density is desirable, this may result in an inability to maximize property value.*

Limitations on density based on wastewater systems may be physical, environmental, or political. Physical limits occur because above a certain density, it is not feasible or practical to fit a WSAS on a property. Buildings and other improvements take up too much of the available space. The density at which this occurs can be increased through use of advanced pretreatment systems which allow downsizing of the WSAS, or through onsite reuse of effluent; for instance, recycling treated effluent for toilet flushing (which requires a very high level of treatment that may itself be space-limited). At some point, onsite treatment becomes infeasible[29] and offsite treatment is required, whether through cluster systems or centralized systems. Cluster systems may also be impractical once a certain overall density of the area served is reached.

Environmental limitations may be reached well before strictly physical limits are reached. For instance, concerns over ground water contamination often lead to large-lot zoning in unsewered areas, with two to five acre lots not uncommon.

Higher value accrues to the owner of land (and the relevant taxing authority) if it can be developed more densely. This is amply shown in the literature on real estate value (Boykin and Ring 1993; Wentling et al. 1988). The question of permitted density is as much a political question as a technical question; it may be that adequate protection to the public health and the environment would be provided by conventional onsite systems at higher development densities than is permitted in many areas, and it is certainly the case that advanced pretreatment can further push back the threshold for physical and environmental concern. Where that is not the case, any wastewater treatment technology which makes denser development acceptable can increase land value. Sewering to allow for offsite treatment at the cluster scale or above is an obvious approach. In particular, centralization is often pursued because it effectively removes site-level physical and environmental constraints on density, thereby allowing maximization of development density according to market conditions.

Note that density limitation can also be considered a benefit of decentralized systems. This angle is addressed in §9.1 on the relationship between wastewater infrastructure and growth.

Decentralization benefit: *Advanced decentralized systems may allow the development of otherwise undevelopable property, thereby creating or maintaining property value.*

Advanced decentralized systems may allow development of land that could not be adequately served by conventional septic systems (due to environmental concerns, for instance) or cost-effectively sewered. Indeed, environmentally and politically acceptable wastewater treatment can make the difference between whether a property may be built on at all, or even whether an existing house must be destroyed. In Massachusetts, the local authorities prescribed that a house on an eight-acre lot must be destroyed at the time of land sale, because the soil's hydraulic gradient connected with a nearby town's well field. An advanced onsite system with blackwater composting and a recycle loop for the graywater satisfied the authorities, who allowed the lot to be sold with the house intact (Schoenborn 2000).

In all cases, developers will do whatever is needed, within their budgets and profit requirements, to develop their properties. They will use the cheapest approach (onsite, cluster, or conventionally sewered) given what the land, local regulations, and local wastewater systems costs permit. Assuming their market

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[29] In practical terms for most situations. However, decentralized systems are possible in very urban areas. In many Japanese cities, onsite systems that recycle water back for toilet flushing are required for buildings over a certain size. The treatment units are typically located in the building basement. System costs are considered cost-effective because potable water is in short supply (Asano 2002, p. 31; Ogoshi et al. 2001).

analysis is correct[30] and the developed property is salable at the expected price, they can then pass on the wastewater systems costs to the purchaser.

10.6.3 Affordability

Decentralization consideration: *Serving areas with decentralized systems rather than sewers can affect the affordability of properties.*

The impacts in this area can cut different ways:

- Just as centralization can increase property value, decentralization (i.e., not sewering) can also help keep properties affordable. Unsewered lots may be more affordable because the value of easy access to a central wastewater system—a type of system preferred by many homeowners, as noted above in §10.1—has not been capitalized into the lot value.
- However, large lot zoning for homes using onsite systems can make lot costs unaffordably high for many people, compared to sewered lots. That is, while sewering to increase density realizes greater value per acre developed than large-lot development, the cost per lot is typically less (because sewers enable smaller lots), all other things being equal. This contributes to making lots or homes more affordable.

Conventional real estate valuation techniques can reveal the values created or lost due to different lot sizes. See also the discussion of the land costs of wastewater systems in §11.3.1 on treatment system capital costs.

10.6.4 Siting

Decentralization consideration: *System scale may affect how a building or set of buildings can be located on a property, which may impact development costs and property value.*

A benefit of cluster systems relative to onsite systems is that clusters, by centralizing wastewater dispersal, allow better home siting in some cases. For instance, depending on the lot, soil conditions may require that an onsite WSAS usurp the most desirable house position based on aesthetic considerations, distance from other houses, etc. Similarly, a WSAS may have to be located in a front yard due to soil conditions, which can affect site aesthetics and property value as described in §10.3 above, increase development costs by increasing driveway and utility lengths, or both. Case studies in Lake Elmo, Minnesota and Mobile, Alabama (Pinkham et al. 2004) show that developers value the design freedom afforded by sewering at the cluster scale.

10.6.5 “Greening” benefits

Decentralization consideration: *Some wastewater systems may increase the value of the subject property or adjacent properties because of a perception that the system is particularly novel, sustainable, or valuable environmentally.*

“Living Machines” are known to provide value in terms of public relations and even increased tourism due to their unique use of hydrophilic plants and other organisms to create a visible ecology based on wastewater treatment. Installations at the Ethel M Chocolates factory in Henderson, Nevada and the National Audubon Society’s Corkscrew Swamp Sanctuary visitor center in Naples, Florida have attracted

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[30] A developer’s market analysis may lead to the choice of systems that are not strictly the least-cost, but are chosen because they increase the ultimate sales price of the property. For instance, developer Robert Engstrom (see the Lake Elmo, Minnesota case study by Pinkham et al. 2004), believes that cluster systems are more expensive than conventional septic development, but are more profitable because of the higher sales price possible for each property due to the amenities that clustering allows.

many visitors (Dharma Living Systems 2004). The added economic value of such systems is difficult to quantify but could be determined through a **travel cost** study.

Wastewater treatment wetlands that provide habitat value may provide similar value. This may be more the case with subsurface flow wetlands that do not exhibit overt signs of eutrophication than with surface wetlands that may experience algae blooms and possibly odor problems from algae die-off.

Some property owners are willing to pay a capital premium on certain wastewater systems—installing a non-least cost system for greening reasons. The difference in costs between the preferred system and a least-cost system, determined with standard **cost estimation** methods, is one measure of the economic value of the "greening benefit" to the system owner, though the owner probably does not think about this benefit in those terms. Also, in most cases the market probably does not capitalize this owner-perceived benefit into the value of the property—most people will not share the perception or be willing to pay for it.

10.7 Constraints and costs imposed on land use change

Decentralization consideration: *Decentralized systems displace and constrain other uses of a site to a lesser degree than centralized systems. The cumulative impact of dispersed, lower impacts of decentralized systems in this respect, versus more intense and concentrated opportunity costs of centralized systems, is not clear.*

Wastewater system choices often have an opportunity cost in precluding other land uses. Further, a choice today may foreclose certain options or impose costs for changing the use or intensity of use of land.

- Centralized treatment systems preclude some or all alternative land uses. This impact increases with scale, as systems become larger and more specialized. Surface space taken up by larger treatment plants cannot be used for other purposes. Smaller systems, especially onsite systems, are likely to have substantial portions underground, or to be small enough that other land uses and activities on the site are not pushed out.
- Effluent dispersal systems may or may not preclude other land uses. In this respect, centralized systems with surface water releases may have an advantage. The point nature of such releases requires little space, while subsurface effluent dispersal typical of decentralized systems can require significant space. This land use precludes many others; buildings cannot be cost-effectively placed over a WSAS. However, land used for a WSAS is frequently amenable to other uses, particularly agricultural and open space uses (Eddy 2000).
- Decentralization helps communities avoid future costs of other changes to community infrastructure. For instance, in road widening projects, a large cost is for relocation of public utilities. Interference of sewers with such projects would be avoided by decentralized systems that do not use affected public rights-of-way.

These sorts of opportunity costs are felt at the level of sites and concentrated locations such as an impacted roadway. Centralized systems will have fewer such impacts, but more intense ones. The relative economic cost of centralized and decentralized systems in these respects probably depends on both the numbers of sites so-impacted, and whether the costs are "real." These costs are only real to the extent the desired alternative uses cannot be accommodated in some other location or manner at no cost. For instance, while a wastewater absorption field may not be available for building a garage, if the garage can be built on another portion of the site without additional cost or compromised value (e.g. aesthetic impact), no real cost is imposed by the absorption field.

10.8 Construction impacts

Decentralization benefit: *In retrofit and repair/replacement situations, decentralized systems generally require less disruption of properties and neighborhoods.*

In new development, differential onsite and neighborhood impacts of installing different types of wastewater systems are essentially not a concern, as residents are not yet in a position to be disturbed. Impacts to neighboring properties from the noise and sights of wastewater system construction are lost in the impact of construction of the overall development. However, in situations where a wastewater system is being installed or replaced for an already developed property or neighborhood, the impacts of construction are often a concern. These impacts can include:

- Temporary aesthetic impacts—the noise, odors, and visual disruption of the construction activity itself, primarily resulting from the operation of heavy equipment and the displacement of excavated soil.
- Disruption to traffic flows from movement of backhoes and dump trucks during excavation activities, particularly if those activities take place in or adjacent to a public right-of-way. Closures of streets may sometimes be necessary. Time and discomfort costs are imposed on travelers when traffic flows are disrupted.
- Business losses resulting from disruption of traffic flows; e.g., where a street closure temporarily prevents access to a business or businesses.
- Damage to vehicles from disturbed street surfaces (dirt, potholes, etc.) and accidents resulting from construction activity or re-routing of traffic.
- Temporary rerouting or permanent movement of other utilities, such as buried gas and electric lines.
- Replacement costs for trees, lawns, sidewalks, driveways, walls, fences, street paving, and other property or right-of-way features.
- Loss of value for trees and other landscaping that cannot be effectively or completely replaced.

The severity and distribution of any impacts depend strongly on the particular system configuration. Onsite systems create a point impact, in some cases a large one, for excavation of the space for treatment units and a WSAS field. Onsite systems also require some amount of linear impact for placement of lines routing flows between the building, treatment unit, and WSAS, and possibly for access of equipment across the lot to the construction zone. These requirements can create severe property disturbances in some cases. STEP/STEG systems also create a point impact for the septic tank, but none for a WSAS. Clustered (including STEP/STEG) and centralized systems require a linear impact for sewering. The type of sewer affects the level of impact. Conventional gravity sewers create the greatest impacts, while low pressure and vacuum sewers have lower impacts because they can be more easily routed around objects, they typically require less time to install, and they have other construction advantages.

The following general tendencies occur regarding the comparative impact of different wastewater system architectures:

- Onsite system construction impacts primarily occur onsite (on the lot, but not in the street or other public areas), while sewered systems (cluster and centralized) create both onsite and offsite impacts.
- Retrofits and replacements of onsite systems are typically more distributed in space and time, occurring as individual systems fail or require upgrading. Sewering typically occurs throughout a neighborhood or entire community in a single time period, creating a larger area that is intensively disrupted for days or weeks.

- Large sewering projects can disturb very large areas. For instance, a proposed scheme to replace onsite systems with sewers in Los Osos, California (population 14,000) will require disruption of 42 miles of streets (Owen 2002).
- The linear impact of trenching for sewers is more likely to disrupt key landscape features, streets, sidewalks, utilities, and so forth than the mainly point impact of onsite system construction. This is a matter of simple geometry: locating a point within a network (of streets, sidewalks, utilities, rows of trees, etc.) is less likely to create overlaps than placing lines or overlaying a whole new network on an existing network. However, it should also be remembered that the smaller the lot, the more likely it is that a point impact (including temporary piling of excavation spoils) will impact key existing features.
- Equipment access to an onsite system location may create a linear impact, but this is often less significant because it is a surface impact only (as opposed to trenching for line placement) and there may be more freedom in choosing the access route than in locating a sewer lateral.
- Small sewered systems (clusters versus more centralized systems) are more likely to employ sewer technologies that allow less impact than do gravity sewers typically used in larger sewered systems. Gravity sewers typically require more extensive trenching than low pressure and vacuum sewers, and cannot be as freely located (e.g., curved around obstacles) as alternative sewers (see §11.2.1).
- The larger the system, the larger the sewers, and the larger the per-foot impact of trenching for their installation or replacement.

It should be remembered that many of the aesthetic and other impacts of repair or replacement of collection systems can be avoided or mitigated by use of trenchless construction techniques (Jennings 1995). Such techniques can also reduce the impacts of installing sewers in existing neighborhoods. They may also be less expensive than trenching because the costs of restoring streets and properties can be greatly reduced. The relative temporary and lasting construction impacts (as well as the construction costs, considered in §11.2.1) of non-sewered systems, alternative sewers, and conventional sewers, and of trenched versus trenchless construction techniques should be carefully evaluated.

A competent engineering analysis within a facilities planning process will take account of readily apparent physical impacts of construction such as restoration costs and relocation of utilities. Restoration costs include such items as replacing pavements and trees, seeding or re-sodding of lawns, rebuilding of walls, fences, and other structures, and so on. These are real, monetary costs that are relatively easily quantified through conventional **cost estimation** techniques.

Qualitative approaches can be used to evaluate the importance a community places on other construction impacts. Where quantification of economic losses from construction impacts is desirable and worth the effort (this would likely be the case only for very large projects), several types of analysis are of potential interest:

- Loss of significant trees, landscaping, and structures may be reflected in property values, which can be assessed using standard real estate appraisal techniques, or **hedonic valuation** techniques.
- Loss of shade trees may also affect the energy cost of building operation. Energy models are available to estimate such increased costs. The effort of their application would rarely be warranted, but representative figures on the energy value of shade trees may be available from state energy offices and Extension Service sources.
- At a broad scale the loss of the value that trees and other landscaping create by reducing the urban heat island effect and reducing stormwater runoff can be estimated with the CITYgreen model created by the nonprofit organization American Forests. To obtain the model or learn more, visit www.americanforests.org/campaigns/ecological_services/).

- Business losses can be estimated by surveying affected businesses to determine the value of daily business, or estimating this value from sales tax revenue records. This value would then be multiplied by the number of days of disruption and some estimate of the percentage loss in business.
- There is an extensive literature on valuation of time lost due to travel disruptions. Cromwell et al. (2002) review this literature for application to valuing social costs associated with failed water mains, a similar topic to installation or repair of sewer lines. The costs of such disruptions depend on the amount of time lost and the value of that time, which has two components, the opportunity cost of the lost time, and the disutility cost of discomfort or other negative aspects of the delay. The authors describe and compare a variety of approaches available for the determination of the value of travel time: mode choice analysis, route choice analysis, speed choice analysis, dwelling choice analysis, and stated preference analysis (**contingent valuation**).

11 Capital and O&M costs

This chapter addresses capital costs and operation and maintenance costs (O&M), which together constitute the focus of traditional engineering economics. These costs are distinct from considerations of financial economics such as forecasting risk, debt carry costs, financing fees, etc., which are treated in §8 on financial planning and risk.

Most of the issues identified in this chapter can be addressed with standard **cost estimation** techniques, cost engineering, and the time value of money tools of **engineering economics**. Their evaluation should be straightforward for engineering firms knowledgeable in centralized and decentralized technology options. However, it is important to remember that many engineering firms are not well-versed in decentralized options. Without solid knowledge of costs across all relevant system scales, the economic evaluation of options will almost inevitably be skewed toward more familiar centralized systems.

Treatment system capital costs typically reveal economies of scale (costs per unit decrease as size increases). This is well-documented, and obtaining economies of scale in treatment—and operations—is often the focus of facility planning. This focus must be carefully moderated, however, because *diseconomies* of scale (costs per unit *increase* as size increases) often occur in collection systems. Because collections systems often account for 70–90 percent of total wastewater system capital costs (Otis 1997; U.S. General Accounting Office 1994), diseconomies of scale in a collection system can offset or overwhelm economies of scale in treatment plant size (Adams et al. 1972) and O&M.

The basic dimensions of the tradeoffs between treatment system economies and collection system diseconomies have been understood at least since the classic work of Adams, Dajani, and Gemmell published in 1972, which identified basic cost functions for both treatment and collection systems. Analyzing the tradeoffs between treatment and O&M economies and collection system diseconomies is a key task of regional wastewater facility planning (Whitlatch 1997), and it should be so for any evaluation within or between different levels of wastewater system scale.

Communities must be sure *all* capital and operational costs are addressed in the facility planning process. This can sometimes be difficult when different system architectures are under consideration. Centralized and decentralized options often differ substantially in the number, types, and costs of capital components and in the types and amounts of O&M costs. As discussed in Part I, comparison of individual component costs should be de-emphasized. The net, "whole system" costs and benefits are the ultimate concern. Thus, after first reviewing capital costs and O&M costs, this chapter concludes with a discussion of the net results of tradeoffs between economies and diseconomies of scale in wastewater systems.[31]

11.1 Capital costs: treatment facilities

Decentralization cost: *Smaller systems miss economies of scale in wastewater treatment systems.*

Treatment facilities have long been thought to enjoy economies of scale—costs decrease per capita as the population served, and thereby the facility size, increases (Hovey et al. 1977, citing Tihansky 1974). For treatment system capital costs, studies before and since the 1972 work by Adams et al. agree that treatment system capital costs can be represented by an equation that takes the form:

[31] The reader is reminded that the net results discussed at the end of this chapter still do not constitute a whole system analysis. Additional costs and benefits of centralized and decentralized options discussed in other sections of this report must also be considered.

$$T = aX^{\beta}$$

Where: T is the total cost for treatment systems,
a is a coefficient,
X is the population served, and
β is an exponent with a value less than 1 representing economies of scale.[32]

The economy of scale factor, β, for treatment systems has been found to be remarkably consistent across technologies, and is about 0.7 (Heaney et al. 1999).

Economies of scale can be represented graphically with a "cost curve," by indicating size of a system (in flow, population served, or other metric) on one axis, and cost per unit size on the second axis. For example, Geenens and Thoeye (2000) investigated the capital costs of a variety of wastewater systems in Belgium. Figure 11-1 shows the capital cost (excluding installation costs, which are highly variable for small systems) per person equivalent (PE) for systems ranging in size from one household (5 PE) to four households (20 PE).[33] Figure 11-2 reflects Geenens' and Thoeye's findings on capital costs (in this case including installation costs) for somewhat larger systems. These figures are included here not for the specific cost information (which varies from U.S. costs because of differing design criteria) but to illustrate several concepts:

- Both graphs show typical economy of scale cost curves, where cost per unit (in this case, person equivalents served) decreases as the number of units increases.
- Different technologies have different cost curves. For instance one technology's cost curve may be lower than another's (i.e., the technology is less expensive at every point of scale). This alone does not make that technology superior. For one thing, each of the technologies shown produce effluent of different quality. For another, a technology with a lower capital cost could have higher operating costs or other disadvantages.
- One technology's cost curve may be steeper than another, indicating stronger returns to scale across the range of scale considered.

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[32] When β is less than 1.0 unit costs decrease as the population served increases.

[33] In the U.S. and in Europe, average household sizes are considerably less than five persons per household. Equating one household to 5 PEs may reflect hydraulic load calculation requirements for wastewater systems in Geenens' and Thoeye's study area rather than actual household sizes.

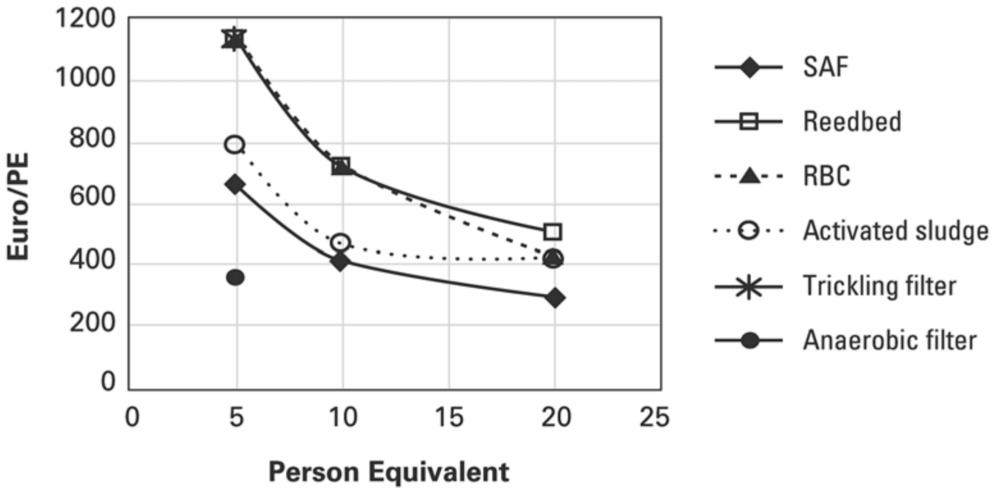

Figure 11-1: Capital Cost Per Person Equivalent for Individual and Small Cluster Wastewater Systems in Belgium. Note: SAF stands for submerged aerated filter; RBC stands for rotating biological contactor. *Source: Adapted from Geenens and Thoeye (2000), Figure 4. Used by permission of the copyright holder, the International Water Association.*

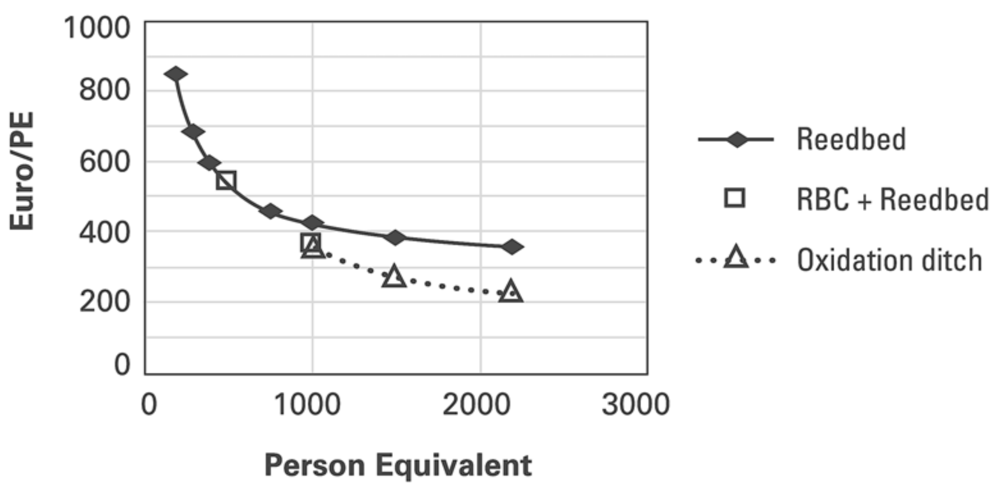

Figure 11-2: Capital Cost Per Person Equivalent for Wastewater Systems Serving 200 to 2,000 Person Equivalents in Belgium. Note: The reedbed technology is a two-stage reedbed; the RBC plus reedbed is a rotating biological contactor plus a simpler reedbed. *Source: Adapted from Geenens and Thoeye (2000), Figure 5. Used by permission of the copyright holder, the International Water Association.*

Returns to scale for treatment systems depend upon a number of fundamental issues:

- sizing of plants relative to the expected hydraulic and mass loads;
- effluent standards and the treatment processes used to achieve those standards;
- the relationship of process unit containment geometries and treatment train configurations to amounts of materials;
- economies in construction time and costs; and
- other factors.

This section treats each of these issues individually in turn. Decentralized systems have a variety of advantages and disadvantages relative to each of these treatment system cost factors.

11.1.1 Wastewater loads: effects on plant sizing and treatment process

Decentralization cost: *Very small wastewater facilities require higher capacity per capita in order to manage variability in hydraulic loads produced per connection.*

Individual wastewater generators may produce hydraulic loads that vary widely over time. The classic case is a residence where on the one hand occupants may be away on vacation and the loading rate is zero, or on the other hand may include guests that raise the short-term hydraulic load substantially. However, the more residences connected to a system, the more these variations average out.[34] Thus, systems serving individual or small numbers of residences must have more capacity per connection, while larger systems can reduce the assumed flow per residence, thus lowering the necessary capacity per connection and achieving an economy in the total system capacity. This "large number smoothing" of variations in actual use occurs fairly rapidly as the number of residences on the system increases. The average flow rate per household per day typically reaches a stable point once system size reaches 50 households (Metcalf & Eddy Inc. et al. 1991, p. 1018). Smaller systems require extra capacity per household in order to accommodate a higher peaking factor (the ratio between maximum flow and average flow). This requirement is typically built into minimum design flows (e.g. sizing of soil absorption fields based on the number of bedrooms) for onsite and small systems in wastewater codes.

User type also affects the necessary capacity. Peaking factors, and therefore the necessary capacity per connection, can be considerably higher for non-residential facilities than residences.

Decentralization consideration: *Smaller systems are more likely to use alternative sewers that do not require extra treatment plant capacity to manage infiltration and inflow loads typical of gravity sewer systems.*

Gravity sewers are subject to infiltration of groundwater through cracked and disjointed pipes, and to inflow through manholes and legal or illegal connections of stormwater lines. Rates of inflow depend upon the configuration of the sewer system (e.g., whether cellar or foundation drains are plumbed into the system). Rates of infiltration depend upon many factors, including the age of the system, groundwater levels, types of soil, types of pipe, quality of the installation of pipes, sizes of pipe, and the length of pipe in the system. Infiltration can vary from 100 to 10,000 gallons per day per inch-mile[35] or 20 to 3,000 gallons per acre per day (Crites and Tchobanoglous 1998, p. 174). Clearly, infiltration affects the peak flow rate of a gravity sewer system and thereby impacts the capacity needed at the treatment plant.

For systems using conventional gravity sewers, the I/I allowance can be considerably more than the end-use flows. If the effect of population density on pipe length per connection is examined (see §11.2.2 below), then the dominance of I/I becomes apparent. Table 11-1 shows how an assumed I/I rate of five gallons per day per foot of pipe exceeds the base wastewater flow rates when the population density drops below about five dwelling units per acre. These figures only address infiltration to a sewer main running down a street. Most studies show that 50 percent or more of total system I/I comes from private on-lot laterals. Larger lots (lower density) would typically have longer laterals, so the effect of lower density on pipe length and I/I would be further pronounced. Serving low-density development with conventional gravity sewers requires substantial capacity above wastewater flows from buildings, in order to account for I/I. Thus, as density decreases, onsite systems and cluster systems using alternative sewers have the advantage of avoiding the capacity penalty that occurs in centralized systems using gravity sewers.

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[34] See also §14.3 regarding the impact of flow variations on the performance of treatment systems.

[35] Multiplying the diameter of pipe by the number of miles of corresponding pipe size, for all pipe sizes in the system, gives the number of inch-miles.

Table 11-1: Effect of Dwelling Unit Density on Sewer Main Infiltration and Inflow

Dwelling Units Density (DU/acre)	Lot Width or Frontage (ft./DU)	Assigned Feet of Pipe[1] (per DU)	I/I Daily[2] (gal./DU)	Indoor Daily Use (gal./DU)
10	22	11	55	180
8	42	21	105	180
6	62	31	155	180
4	82	41	205	180
2	140	70	350	180

1) Assigned pipe length equals 0.5 * lot width (pipe is shared equally with lot across the street)

2) Assumed I/I is 5 gallons per day per foot

Source: Based on Heaney et al. (1999), Table 10-2.

For onsite systems and cluster or small plant systems, especially those using shallow trenching, pressurized sewers, and/or continuous small-diameter pipe, sewer I/I is non-existent or low (Otis et al. 1981). Pressurized sewers, often used in cluster systems, often use small diameter continuous piping that is less susceptible to being compromised, and the positive pressure in the pipe prevents infiltration if the pipe is compromised. Vacuum sewers can become compromised, but essentially stop working when a leak occurs, and the problem is usually easily located. Infiltration to gravity sewers, on the other hand, is an insidious problem that typically increases slowly over time and may be quite dispersed through the sewer network.

New sewer technologies, including glued or continuous pipe for sewer laterals, better sewer main joints, and improved pipe bedding practices should reduce I/I in gravity sewer systems. This could allow reductions in I/I allowances and downsizing of treatment plant capacity. However, engineers differ on how well the new technologies will prevent I/I and the wisdom of reducing I/I allowances. Much depends on other factors, such as local soil conditions (e.g. shrink-swell soils).

It should be noted that centralized systems can avoid much of the I/I issue by utilizing the same alternative sewer technologies used in many decentralized wastewater systems. This is increasingly being done. Instances include Hillsborough and Sarasota counties in Florida, and Ocean Shores, Washington, to name a few (Anderson 2004).

Another consideration is that decentralized systems can be susceptible to I/I through a different means: non-watertight septic tanks. Depending on tank materials and construction, water can infiltrate into septic tanks. It is not known how prevalent this problem is—unless a soil absorption field experiences hydraulic failure (surfacing of effluent) or the onsite system includes a pump which is noticed to run more than should be expected, infiltration to a septic tank will go unnoticed. On the one hand, unlike in the case of I/I allowances for gravity sewers, this potential problem has not resulted in wastewater codes including I/I allowances in the sizing of soil absorption fields or other decentralized system components. On the other hand, savvy operators of cluster systems that include onsite septic tanks are keen to avoid this potential source of system failure. For instance, Tennessee Wastewater Systems, Inc., a privately owned decentralized wastewater utility that operates over 40 cluster systems in 23 counties in Tennessee, reportedly designed their own septic tank in order to ensure watertightness and thereby avoid problems with unplanned flows in their cluster treatment systems (Lee 2004).

Decentralization consideration: *Minimum design flow requirements may result in onsite and cluster systems that are underloaded, affecting their ability to function properly.*

Most state and local codes governing small wastewater systems include standards that require onsite and cluster systems to be sized according to prescribed minimum flows. Typically a minimum flow per bedroom is established, and additional minimum flows per employee or square foot or other metric for commercial and institutional buildings are common. These minimum design flows are usually conservative, to ensure that systems are not undersized. However, it is important to realize that certain alternative and advanced onsite and cluster-scale wastewater treatment systems require certain loadings relative to their capacity in order to function properly. This issue is particularly important for cluster systems. Unless the system includes modules that can be added as demand grows, a cluster system sized for ultimate buildout may not function well in early periods, when the system is underloaded.

Decentralization consideration*: Decentralization can be used to isolate waste generators that produce high hydraulic or mass loads (e.g., BOD loads of restaurants, hydraulic and pollutant loads of industrial facilities) in order to reduce the capacity and treatment needs such facilities place on public systems.*

During the wastewater facility planning process, when a service area for a multi-connection facility is defined, questions of technical efficiency and of equity may arise if some connections produce particularly large hydraulic loads, high-strength wastewater, or wastewater with special constituents not contributed by other users. It is possible to centralize treatment for all the various users, or to centralize treatment for most users and use onsite or cluster systems for connections that produce divergent loads. The latter strategy can reduce costs for most users and place any above-average costs directly on those whose wastes require extra capacity or special treatment. However, two other strategies are far more commonly used. One is to require onsite pretreatment of high-strength or unique loads prior to disposal to a common sewer. Another is to implement rate structures that charge users according to the quantity and/or the quality of their waste loads. Determining the most economic strategy will depend upon the location and amounts and types of the various loads. Equity and political feasibility may also be considerations.

11.1.2 Effluent standards

Decentralization cost: *High effluent standards tend to favor centralized treatment.*

In general, the higher the effluent standard, the higher the capital cost, at any given scale, of systems that can produce the desired effluent quality. For example, Freedman and Stallings (2000) modeled how different levels of phosphorus removal would affect capital costs for retrofits to five small wastewater treatment plants in Main and New Hampshire, as shown in Figure 11-3.

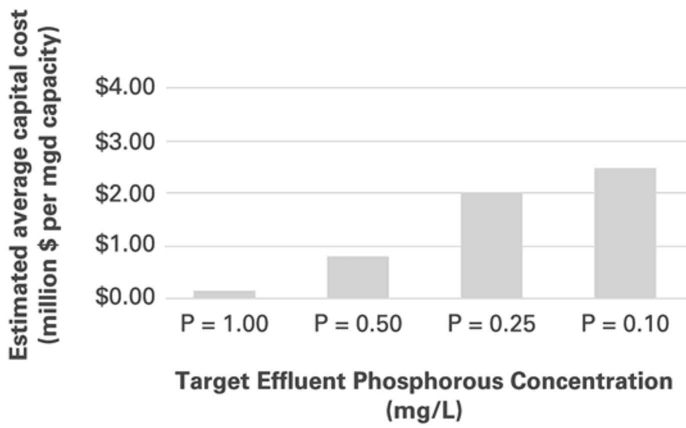

Figure 11-3: Estimated Unit Capital Costs to Achieve Specific Phosphorus Concentrations for 5 Small New England Wastewater Treatment Plants (January 1999 dollars, based on ENR20 cities index = 5,950). *Source: Adapted from Freedman and Stallings (2000), Figure 2. Used by permission of the New England Water Environment Association.*

Decentralized technologies are capable of removing high percentages of pollutant and producing very high quality effluent with low pollutant concentrations (Anderson and Otis 2000, pp. 222–227). However, high performance decentralized systems can be costly. Clustering can bring down costs substantially compared to individual onsite system, but for very high effluent standards, larger centralized systems will often be more economical. For instance, in a wastewater master plan completed for the Florida Keys in 2000, centralized systems were found to be more economical than decentralized systems for 26 of the 29 study areas within the Keys (Lindahl Browning Ferrari & Hellstrom Inc. 1999, pp. 8 –12).[36] Based on state regulations for the Keys, onsite and cluster systems were required to meet a 10 mg/l effluent standard for total nitrogen. This required costly "OWNRS" (Onsite Wastewater Nutrient Reduction System) technology. Had the standard been slightly more lenient, onsite or cluster systems would have been the choice for many more of the study areas, according to the engineer responsible for the decentralized system analysis of the master plan (Anderson 2003).

11.1.3 Materials

Decentralization cost: *Smaller treatment systems typically require more material per unit of capacity.*

Physical plant (the amount of material in pipes, tanks, pumps, etc.) per unit of capacity typically decreases as the number of units served increases, due to simple geometries of physical containment. For example a larger basin has less surface area per gallon contained than a smaller basin. Therefore, the cost of materials incorporated into smaller systems is usually greater per unit of capacity than that for larger systems.

However, it should be noted that new, advanced treatment technologies, such as systems using membranes, are often manufactured and installed in smaller, modular units. This reduces the material

[36] See also Volume I of the master plan (CH2M HILL et al. 2000). System recommendations were based largely, but not entirely, on costs. The cost estimates that resulted in the centralized/decentralized allocation have been controversial. Since release of the plan, some local stakeholders and some outside experts have claimed the cost estimates for centralized systems were too low and the cost estimates for decentralized systems too high. Other experts claim that the decentralized system cost estimates were too low.

economy of scale enjoyed by larger facilities. Purchasing economies (cost per unit decreases as the number of units purchased increases) may still apply.

Larger treatment facilities may have a greater need for redundancy or backup of certain, often expensive, components, because the consequences of failure are greater. For instance, many centralized plants require backup power generation, while onsite and small cluster systems seldom do.

11.1.4 Construction[37]

Decentralization consideration: *As system scale decreases, per unit costs of treatment plant construction typically increase.*

Typically there are returns to scale on construction costs. For example, the ratio of value-adding construction time to equipment transport and job start-up time and costs increases for a large system compared to a number of small systems. As another example, larger, more efficient construction equipment can be used on larger projects.

However, there may be limits to these economies. For very large centralized plants requiring many months or even years to complete, the likelihood of construction delays due to contingencies, labor problems, or other issues increases. Such delays may bring direct cost increases, and are also costly because they increase the span of time during which project financing costs are carried but no revenue from the plant is available.[38]

Decentralized systems have some construction cost advantages in that decentralized technologies tend to be simpler to build than many centralized systems—compare construction of sand filters to construction of an activated sludge treatment plant—and therefore do not require expensively scarce construction management talent. However, decentralized wastewater professionals have noted that poor installation of onsite systems is not uncommon, so “any guy with a backhoe” may not be sufficient construction talent. A knowledgeable equipment operator or supervisor is usually required. Still construction talent for decentralized systems need not be as sophisticated as that necessary for a major centralized treatment plant project.

It is important to note that areas new to decentralized technologies (that is, to advanced decentralized technologies; septic systems are fairly universal) may have higher construction costs due to contractor unfamiliarity with the installation requirements of the technology. Cost gouging is even known to occur. These cost premiums will likely decline substantially with time.

11.2 Capital costs: collection systems

Decentralization benefit: *Smaller systems avoid diseconomies of scale in wastewater collection systems.*

Collection systems often experience diseconomies of scale—costs increase per capita with increasing system size (Hovey et al. 1977; Tihansky 1974). The collection system capital cost function is more complex than the equation for treatment system capital costs. One approach to this cost function, put forward by Adams et al. (1972) consists of two terms: basic network costs plus penalty costs. Basic

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37 The term “construction cost” as used here and in the section on capital costs of sewers refers only to the costs of installing a treatment plant (or putting sewer pipe into the ground). Engineers and others often use the term “construction cost” to mean the combined cost of materials and installation. Unless specifically clarified to the contrary, later discussions use the terms “constructed cost” or “installed cost” to denote combined material and construction costs.

38 This may not be an issue for public systems where rate increases do not necessarily have to be tied to project completion, as is usually the case for regulated private utilities.

network costs are costs for fully utilized lines, which exhibit economies of scale. Penalty costs are costs for underutilized lines, which exhibit diseconomies of scale and are added to the basic network costs.[39]

While not articulated by Adams, Dajani, and Gemmell, the notion of underutilized lines has two important dimensions. First, since sewer capacity is typically installed for the collection area's build-out population, most sewer capacity is underutilized for many years. Second, in many places codes specify minimum pipe sizes. At the neighborhood level, these specifications are typically larger than truly necessary, so large amounts of pipe in the network are permanently utilized below their capacity.[40]

The total collection system cost, according to Adams, Dajani, and Gemmell, is the sum of the following two equations:

Network Cost $= aA^{\alpha}D^{\delta}$

for $D \geq d$

Penalty Cost $= A^{\alpha}(bD^{-\gamma} - c)$

for $D \leq d$

Where: a, b, c are coefficients,
A is the gross area served in acres,
α is an exponent with a value greater than 1.0,
δ and γ are exponents with a value less than 1.0,
D is the gross population density in persons per acre, and
d is the density of population beyond which all links (pipes) are utilized to their design capacity.

Adams et al. show examples where α is 1.17, δ is 0.30 and γ is approximately 0.35. The total collection systems capital equation suggests the existence of diseconomies of scale, as the population or area served increases at a given population density.

Returns to scale for collection systems depend on a number of issues:

- construction requirements (e.g. deep trenching or not).
- population density of the service area and its affect on pipe lengths;
- total population served and its affect on pipe size;
- manhole requirements; and
- needs for lift stations, vacuum stations, and other pumps.

The first three issues are treated in turn below, followed by a section that looks at the net effects of pipe length, size, and construction costs on returns to scale for pipe networks. These returns are shown to be negative (diseconomies of scale) for conventional gravity sewer systems when populations served are greater than 1,000. Smaller systems with less length of sewer pipe and alternative sewer systems are likely to enjoy advantages. Later sections address the manhole and pump factors noted above, which may also work to the advantage of smaller systems.

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[39] Adams et al. (1972) classified main lines as fully utilized and lateral lines as underutilized. It is not clear why they made this categorical distinction, which probably rarely holds. However, the concept of differentiating fully and partially utilized lines in addressing economies of scale should hold regardless of the mains/lateral distinction made by Adams et al.

[40] Unless infiltration and inflow take up or overload this capacity. See §11.1.1.

11.2.1 Construction

Decentralization benefit: *Smaller systems can avoid the high costs of installing large pipes and can take maximum advantage of alternative technologies that cost less to install.*

Smaller pipe diameters in cluster or small-scale systems can allow use of continuous rather than sectional pipe and non-gravity systems that can be diverted around obstacles, yielding reduced excavation costs. Smaller collection systems may reduce one or more of the following trenching cost components: depth, width, de-watering, and trench box use. Note that these cost sources are often reinforcing: e.g., deeper trenching for conventional gravity sewers is more likely to require de-watering and trench boxes. Further, avoiding the precise laying and bedding required for gravity sewers reduces costs. Finally, smaller pipes are more amenable to trenchless installation technologies, which can reduce costs in some situations; for instance, by reducing costs to replace driveways, lawns, and other landscaping that would otherwise be torn up by trenching. In some places local codes may preclude these advantages; for example, by requiring certain pipe depths.

Specific conditions such as high water tables, shallow bedrock, presence of other utilities, and other conditions can increase the construction costs of sewers considerably. Cluster systems may avoid some of the most difficult areas, or provide construction savings through reduced trench lengths, reduced trench depths, or other factors. Onsite systems can avoid expensive sewer construction altogether. For instance, on Washington Island, Wisconsin, onsite systems and holding tanks were the only economically feasible options due to the estimated costs of installing sewers in the island's shallow bedrock (Pinkham et al. 2004). However, conditions like those just mentioned also affect the onsite technology choice—potentially resulting, for instance, in mounded soil absorption fields that increase the onsite system cost. Trade-offs between construction costs, technology costs, and other factors must be carefully considered.

11.2.2 Population density and length per service

Decentralization benefit: *Smaller systems have shorter pipe lengths per connection served*.

Collection system economies are highly dependent on land use density: capital costs per connection for systems at typical low suburban development densities are significantly greater than costs at higher densities typical of close-in urban development (Adams et al. 1972). One factor contributing to this diseconomy is the length of pipe required per connection.

In rural areas, pipe lengths per service (connection to a house, business, or other account) can be quite long, making decentralized systems very attractive. As density increases, lengths per service decrease, and collection systems become more economic. Typically higher populations within a service area mean increased density, so the focus in wastewater facility planning is often placed on total population served. However, increasing the size of a service area or combining service areas to increase population served can yield uneconomical results.

As one moves from home to neighborhood to sub-regional to regional scales, increasing amounts of land in parks, schools, roads, parking lots, industrial and institutional campuses, golf courses, lakes, etc., are added, decreasing the density of land use. Figure 11-4 shows conceptually how such areas (revealed by their lack of roads) are included as service area size increases. This results in longer lengths of pipe per connection.

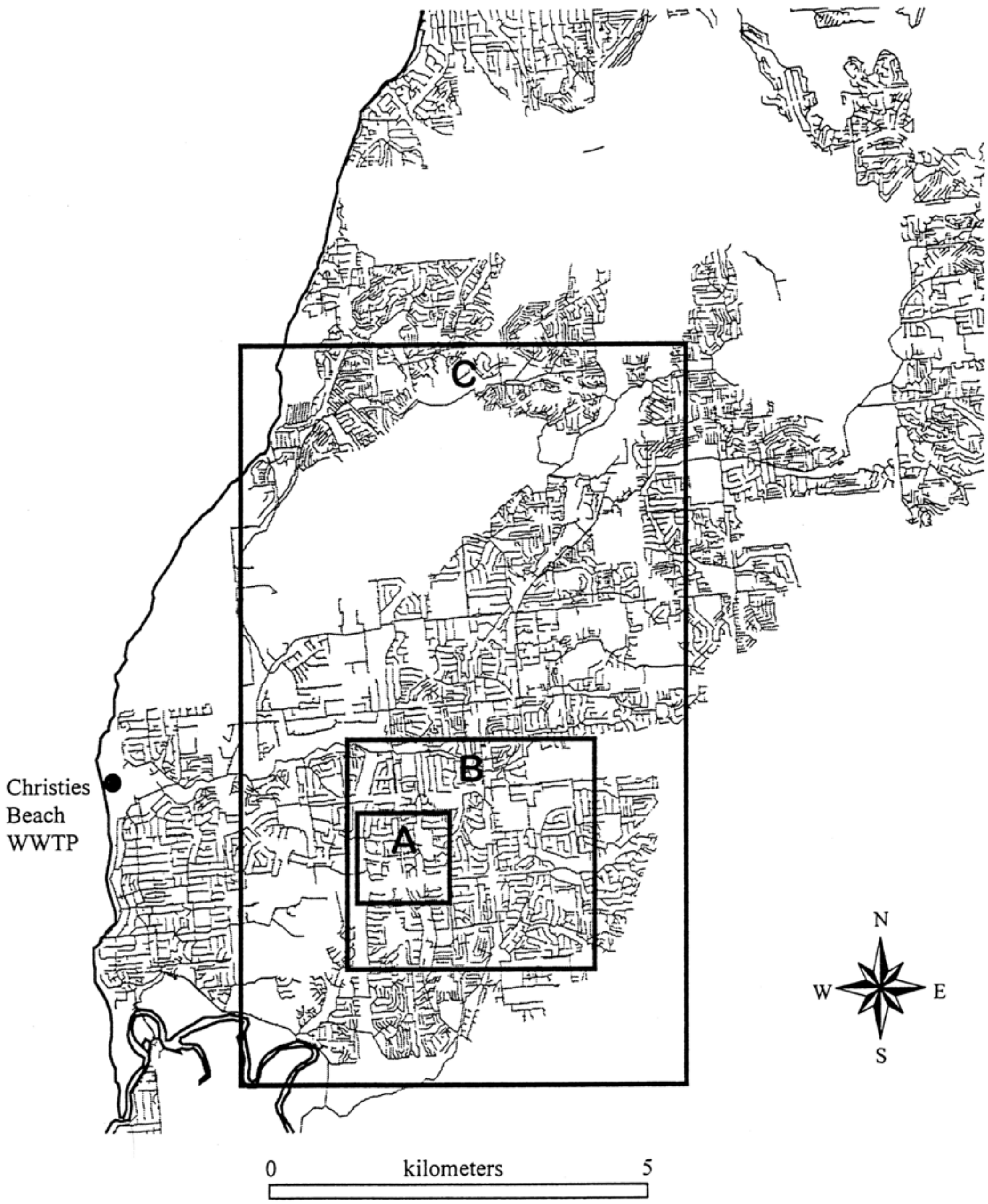

Figure 11-4: Example of Inclusion of Low-Density Areas as Scale of Service Expands. The lines shown represent the sewer network. Low-density (open space) areas are shown by the lack of lines.
Source: Clark (1997), Figure 2.2. Courtesy of Richard Clark.

Figure 11-4 is drawn from a rigorous examination by Richard Clark of economies and diseconomies of scale for Adelaide, Australia, a medium-sized city in a mixed hilly and coastal plain setting (Clark 1997; Clark et al. 1997). Adelaide is served by four conventional wastewater treatment plants that range in size from 50,000 to 190,000 services (accounts) per plant. The collection system in Adelaide shows diseconomies with increasing service area size. These diseconomies include decreasing density and thereby increasing length of pipe per service. Density per service ranges from 750 square meters per service at the level of a typical urban house to 1250 square meters at the residential subdivision level to 1855 square meters at the metropolitan scale. Pipe lengths per service range from theoretically zero at the onsite treatment scale[41] to 11.6 meters at the residential subdivision scale to 15.1 meters at the metropolitan scale. Vis-à-vis land use and collection system diseconomies, Clark's study shows quantitatively that

> …the inherent diseconomy is approximately proportional to the square root of the density of spatial distribution of the services within the network. Thus the size of the diseconomy can be significantly affected by normal land use planning and development practices (Clark 1997, section 1.1).

11.2.3 Total population served and pipe size

Decentralization benefit: *Smaller systems have a lower ratio of large pipes versus small pipes, thus reducing the use of more expensive large pipes.*

For typical gravity sewer systems, Table 11-2 shows the prevalence of larger pipes as the population served increases, based on data from the Dames and Moore 1978 survey of 455 sewer construction projects. The ratio of large pipes to small pipes increases from 0.17 for the smallest systems in the survey (serving 2,500 to 10,000 people) to 0.68 for the largest systems (over 500,000 people).[42]

Table 11-2: Relationship of Population Served to Distribution of Pipe Sizes

Population Range		Mileage of Various Pipe Sizes					Feet of Large Pipe/Feet of Small Pipe[1]
From	To	<8”	8”-14”	15”-24”	>24”	Total	
2,500	10,000	23,987	74,257	12,740	3,787	114,771	0.17[2]
10,000	25,000	19,041	47,946	7,264	2,218	76,469	0.14
25,000	50,000	9,233	34,609	6,749	3,402	53,993	0.23
50,000	100,000	10,061	29,925	6,108	5,236	51,330	0.28
100,000	250,000	5,010	34,824	5,662	4,610	50,106	0.26
250,000	500,000	4,860	26,123	7,420	4,990	43,393	0.40
500,000	>500,000	1,094	39,649	14,971	12,646	68,360	0.68

1) “Small” pipes are those 14 inches in diameter or less; “large” pipes are greater than 14 inches in diameter.

2) Sample calculation: (12,740 + 3,787)/(23,987 + 74,257) = 0.17

Source: Adapted from Heaney et al. (1999, Table 10-4), based on Dames and Moores' 1978 national survey.

The greater prevalence of larger pipe in larger systems is important because, as one would expect, large pipes cost more per foot. Larger pipes have more material per foot, and larger pipes require wider

41 Theoretically the entire on-lot pipe length for on onsite system could be zero, if the treatment system is located inside the building and effluent is recycled. Realistically, short on-lot pipes are required for an onsite system, including house to tank pipes, tank to soil absorption system pipes, and sometimes pipes between different components of a treatment system. Typically the pipe length (not including pipe within the soil absorption system, which is part of the treatment system) would be less than that required for a sewer lateral to a sewer main.

42 Heaney et al. (1999) compare current pipe length ratios from Boulder, Colorado and find that Dames and Moores' 1978 ratios are still reasonable.

trenching and other construction practices that increase the construction costs per foot. Heaney et al. (1999)—again using data from Dames and Moores' 1978 study summarizing the average installed costs (materials plus construction) of sewage piping per foot and average flows carried for pipes ranging from six inches to 72 inches in diameter—show a linear relationship between cost and pipe size:

$$C = 14.99D$$

Where: C is installed cost/foot in 1998 U.S. dollars, and
D is pipe diameter in inches

Heaney et al. also calculate a production function relating cost to the flow carried (which is a function of pipe size):

$$C = 217.66Q^{0.4385}$$

Where: Q is pipe flow in cfs

The sewer pipe costs, flow rates, and costs per unit flow are summarized in Table 11-3, updated to 1998 dollars. The table shows that pipe costs per installed foot increase as pipe size increases and that the cost per unit flow decreases as size increases.

Table 11-3: Relationship of Pipe Size to Cost Per Foot and Cost Per Unit Flow

Pipe Diameter (Inches)	Average 1998 Installed Cost ($/Foot)	Flow Range (MGD)			Installed Cost Per Foot Per Mean MGD
		Min.	Max.	Mean	
6	$56	0	0.08	-	-
8	$101	0.08	0.17	0.125	$808
10	$111	0.17	0.29	0.23	$483
12	$139	0.29	0.47	0.38	$366
15	$172	0.47	0.82	0.645	$267
18	$221	0.82	1.3	1.06	$208
21	$278	1.3	1.9	1.6	$174
24	$292	1.9	2.7	2.3	$127
27	$320	2.7	3.8	3.25	$98
30	$419	3.8	4.9	4.35	$96
36	$506	4.9	8	6.45	$78
42	$588	8	11.8	9.9	$59
48	$710	11.8	17	14.4	$49
54	$793	17	22.5	19.75	$40
60	$983	22.5	29.5	26	$38
66	$1047	29.5	37.5	33.5	$31
72	$1136	37.5	48	42.75	$27

Source: Adapted from Heaney et al. (1999), Table 10-8, based on Dames and Moores' 1978 national survey. Costs updated to 1998 dollars.

11.2.4 Net effects—diseconomies in pipe networks

Although flow rates experience an economy of scale with increasing pipe diameter, this relationship is less important to costs per connection than the relationships of density and population served to pipe lengths and pipe size. Conceptually, for a given population density, Figure 11-5 shows how increasing the population served affects pipe lengths and sizes. The diagram shows four theoretical block of 400 lots (20 lots by 20 lots), with each lot shown by a cross (see the left-most block). The four blocks represent, left to right, different system architectures with a decreasing number of facilities. The left-most block portrays onsite facilities (one for each cross). The next block shows small-scale (cluster) facilities represented by black dots, with a thin black line representing a small diameter pipe. The medium-scale facilities shown in the third block are represented by small open circles. More of the lots are connected with each other, so the pipe length has increased, and some larger pipes are required. Finally, a single, still larger facility is represented. Larger pipes are required to bring the sewage of all lots to it. As Richard Clark notes:

> It can be seen that as the scale of communal servicing rises from individual on-site servicing to the largest grouping, with all allotments sharing in a single communal system, both the total length and the maximum size of pipes required to provide the service progressively increase from zero. Since the number of serviced allotments [lots] remains constant in all cases, the cost per service must also increase as the scale of servicing increases (Clark 1997, section 1.1).

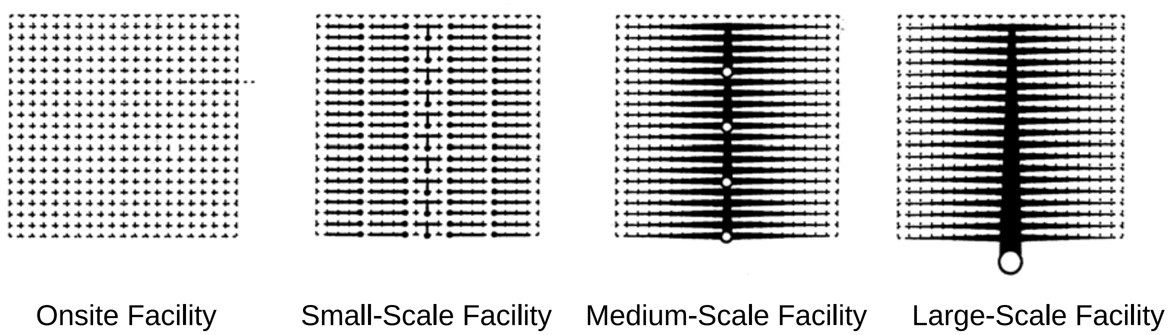

Figure 11-5: Conceptual Illustration of Increasing Pipe Length and Size as the Population Served Increases. *Source: Clark (1997), Figure 1.1. Courtesy of Richard Clark.*

These relationships have been shown quantitatively, using actual sewer cost data and conservative assumptions, by Heaney et al. (1999). They calculate installed sewer costs per connection as a function of: a) dwelling unit (DU) density, and b) population served. The results are shown in Table 11-4. The figures for length of small pipe per DU (assumed to be the sewer main running down neighborhood streets, and not including laterals) are calculated as shown earlier in Table 11-1. The ratios of large pipe to small pipe (0.14, 0.2, and 0.4) for the three population sizes shown are based on a curve fit to the data in Table 11-2. Costs are based on the updated Dames and Moore sewer construction cost data (materials and installation) as shown in Table 11-3. Note that the cost per foot for large pipe (greater than 14 inches) is conservative compared to the figures in Table 11-3.

Table 11-4 shows that for any given population density (rows), the total installed pipe cost per DU increases as population increases. This shows that pipe networks have a diseconomy of scale relative to total connections served. This diseconomy will affect the net returns to scale for the total wastewater system, as discussed later.

The results also show that for any of the three populations (the three right-most columns) the total cost per DU, including small pipe and prorated shares of larger pipes, decreases as density increases. This supports two conclusions:

- Density favors centralization. The more urban the area served, the more likely it is that a larger wastewater system will be most economical.
- However, to the extent expansion of a service area decreases overall density, as discussed in §11.2.2 above, diseconomies will come into play. In such situations, smaller systems (e.g. cluster systems) can take advantage of higher "spot density" while avoiding the low-density penalties that come with extending sewers across a larger area of lower overall density.

Table 11-4: Relationship of Density and Population Served to Pipe Network Costs

Larger/Smaller Ratio:		0.15	0.2	0.4	Installed Cost of Small Pipe ($/DU)	Total Installed Pipe Cost for Various Population Sizes[1] ($/DU)		
Dwelling Unit Density (DU/acre)	Small Pipe (feet/DU)	Added Larger Pipe (feet/DU) for Various Population Sizes						
		1,000	10,000	100,000		1,000	10,000	100,000
2	70	10.50	14.0	28.0	$7,000	$10,150	$11,200	$15,400
4	41	6.15	8.2	16.4	$4,100	$5,945	$6,560	$9,020
6	31	4.65	6.2	12.4	$3,100	$4,495	$4,960	$6,820
8	21	3.15	4.2	8.4	$2,100	$3,045	$3,360	$4,620
10	11	1.65	2.2	4.4	$1,100	$1,595	$1,760	$2,420

[1]Assumed Unit Cost for Pipe in $/ft:

"Small Pipe" $100
"Large Pipe" $300

Source: Adapted from Heaney et al. (1999), Table 10-9. All costs are in 1998 dollars.

The results of Heaney and his colleagues are corroborated by Clark's own quantitative work in Adelaide, Australia (1997). Clark created a pipe system model that incorporates local data on sewering costs for various pipe sizes given typical Adelaide densities. The model shows diseconomies in scale for pipe networks. For a system with 320 services (approaching 1,000 people) the cost per service is $3,000 Australian dollars. The cost per service rises to $5,000 Australian dollars for 60,000 services, due to requirements for longer and larger pipes.

While the two studies discussed above are based only on conventional gravity sewers and the populations shown, it is likely that pipe network costs per connection would continue on a downward trend for smaller populations served. This is because:

- Onsite systems have small house-to-system pipe costs. Total lengths and pipe sizes are shorter than if the house is connected into a sewer network.
- Cluster systems for populations less than 1,000 are likely to use alternative sewers that have lower installed pipe costs per connection than gravity sewer systems.

Large centralized systems can incorporate alternative sewers and gain some of the advantages of their use in cluster systems. However, larger pipes will still be necessary as the population served increases. Therefore, some pipe network diseconomies of scale are likely to occur in alternative sewer systems serving larger populations. The nature of the relationship between alternative sewers and system scale has not been well documented.

The following two sections address some additional collection system cost factors besides the pipe network itself.

11.2.5 Manhole requirements

Decentralization benefit: *Smaller systems may need fewer manholes or none at all.*

For conventional gravity sewers, codes require manholes at regular intervals along sewer pipes. By reducing pipe lengths, decentralized systems may reduce the number of manholes required to serve a given population. Onsite systems avoid manholes altogether. So too do cluster systems that utilize alternative sewers. Such sewers still require access ports, but the costs of ports on alternative sewers is much less than the costs of manholes.

11.2.6 Lift stations and other pumps

Decentralization benefit: *Smaller systems often have lower requirements for pumps than larger systems.*

Larger gravity collection systems may also suffer a diseconomy due to increased pumping requirements. Because gravity sewer lines must be sloped, as distances between services and a plant increase, more pumping units must be in place to bring the sewer water back up to economic trenching depths for line continuation. This requirement and the resulting impact on system cost depend significantly on local topography.

11.3 Capital costs: other aspects

The following sections address the economics of other capital costs, including land, design, and permitting. Larger systems may benefit from economies of scale in these costs. However, diseconomies in these cost items can occur as systems get very large. On the other hand, for decentralized systems, the "transaction costs" of design (planning and engineering) and permitting for multiple small units may present diseconomies.

These various economies and diseconomies may or may not be adequately accounted for in the estimation of centralized or decentralized system capital costs—that is, they may or may not be included in treatment and collection system capital cost estimates prepared by staff or consulting engineers. Communities must be sure *all* capital costs are addressed in the facility planning process, as well as O&M costs and other costs and benefits.

11.3.1 Land and siting

Decentralization consideration: *Land area requirements and siting constraints may favor or disfavor smaller systems.*

Larger plants generally use less land per unit served, because containment economies allow for smaller unit "footprints." However, there may be nuances and tradeoffs to be accounted for. For instance, land for expansion of an existing plant may be unavailable. Large blocks of land for new plants may be difficult to assemble, or very expensive because of their uniqueness within a geographic area and their desirability for other uses. These considerations may push plant location to distant sites, increasing collection system costs.

Centralized treatment plants are frequently located in riparian areas. Historically such areas are cheap, and are also the lowest land point, conducive to gravity collection systems. But the value of riparian land in social and ecological terms if not market price has increased in recent years. It is becoming more undesirable or expensive to locate wastewater treatment plants in riparian zones. This may force treatment plant sites to other sites that may increase pipe lengths, require pumping stations, etc.

For onsite systems, land may not constitute a cost. On suitable sites, buried septic tanks or other treatment units and leachfields may allow use of the land surface. Where onsite systems preclude other desired uses of the surface, they do have a land cost. Also, where lot size is increased for onsite system use, for instance by zoning regulations with lot sized based on the area necessary for acceptable nutrient loading levels, a land cost for onsite treatment is implied. A cluster system may avoid this "incidental" cost by allowing higher density, though it also has a land cost for the cluster treatment unit itself.

Where the land for a treatment system has multiple uses (e.g. lawn areas over leachfields), a complete economic evaluation will account for the value of the land used, even though an "out of pocket" monetary land cost is not apparent. The problem of costing the value of land for a facility that has multiple purposes or functions is a complex one. Sample et al. (2003) have developed a method for allocating costs among multiple purposes based on the opportunity cost of land, and for assigning those costs at the parcel level. The method has been applied to costing of stormwater controls and best management practices, but appears likely to be useful to estimating and allocating the land costs of wastewater systems that have additional land use attributes. Sample and his colleagues detail a breakdown of the total costs of properties into component costs of developing land, constructing buildings, maintaining landscaping, etc., as a method for determining the opportunity cost of land for different types of land use and allocating those costs to stormwater controls. This determination is important "as a possible incentive to customers for providing onsite controls and as an accurate assessment of their fair share of the total cost." The method is to apportion the costs of multipurpose facilities (in this case, stormwater systems), by designing "systems meeting each single-purpose goal and dual and multiple purpose goals. Then the cost of the cooperative facility that meets all required goals is apportioned among the purposes using cooperative n-person game theory." (Sample et al. 2003)

11.3.2 Design and planning

Decentralization consideration: *Smaller systems are more likely to use "off the shelf" technologies, while larger systems tend to require more sophisticated, customized engineering. However, smaller systems may require more sensitivity to site conditions throughout a service area. A decentralized approach may have greater up-front planning costs.*

A host of decentralized treatment technologies—textile filters, trickling filters, peat filters, and more—are available as pre-built, modular units that simplify onsite or cluster system engineering. As systems get larger, the need to customize treatment trains, units within treatment trains, and the overall system (e.g. site layout) increases, adding to engineering costs. The engineering cost difference between "manufactured" and "constructed" systems can be substantial.

However, onsite and cluster systems using standardized technologies can never be entirely a "black box" that is simply "fitted" to a house. Some, and sometimes substantial, analysis of site conditions is necessary in order to locate and design an appropriate wastewater soil absorption field. Across a service area, the fees for engineering services necessary at each installation to satisfy local or state design and siting requirements can add up to a substantial amount.

Such fees may be in lieu of or in addition to the environmental analysis and/or engineering services undertaken as part of an overall community wastewater needs assessment. Studies of soil conditions, watershed hydrology, sensitive environmental areas, wastewater generation, and other factors that vary across a community are typically part of a needs assessment. A needs assessment should be undertaken for any community considering its wastewater options, and to some degree then does not represent a difference between less or more centralized options. However, if a community chooses to go with onsite or cluster systems, additional analysis may be necessary in order to determine what types of decentralized systems are most appropriate for various sub-areas within the community.[43] It is not entirely clear whether such studies, and any additional design fees for each decentralized unit, are more or less costly than the engineering services necessary to design a more centralized treatment plant and collection system. Costs for the latter design task can be especially significant where a sewer is being retrofitted into an already developed area. On the other hand, some experts in the decentralized wastewater field believe that the up-front costs of planning are often greater for a decentralized approach. Among other factors, this could occur because of additional education and community involvement needed to reach a decision to take a decentralized approach rather than a "standard" and commonly understood centralized sewer approach.

11.3.3 Permitting

Decentralization consideration: *The sum of permit fees paid to entities outside the community may be less or greater for decentralized systems than centralized ones. Transaction costs to obtain permits may push decisions toward more or less decentralization.*

Initial permit fees paid to any entity outside the community, in order to enable legal installation of a wastewater treatment facility, represent a capital cost to the community. Permit fees paid to the community itself for installation of onsite or cluster systems should not be considered a capital cost to the system, as these fees are typically cost recovery payments for community investments in a decentralized system.[44] Whether the sum of permit fees paid to entities outside the community is greater for more centralized or less centralized systems will depend on the fee structures established in each county, region, or state, and on how the community wastewater system architecture fits to any size thresholds at which fees per treatment system increase.

Above and beyond the permit fee, obtaining a permit often creates costs for the prospective wastewater system owner. Engineering review and certifications, legal requirements, conformity with zoning and other local regulations, and other "transaction costs" can be substantial. Here are only a few examples of how permitting may affect choice of system scale:

- Developers may go with onsite instead of cluster systems because it is often quicker and cheaper to get zoning and permits for conventional lot layout and wastewater systems (septic) than for cluster system, particularly if clustering of housing units is also involved.
- Advanced decentralized systems may require more effort to get approval from regulators. Regulators in areas new to these systems need to be educated about their efficacy and their O&M requirements, and their legitimate concerns must be addressed. Reportedly, regulators in some states are going slow on decentralized wastewater permitting because: a) the linkages between decentralized systems and growth control are not being well made, and the regulators do not want to take a political hit for growth inducement, and b) management of decentralized systems is spotty, so they are wary of permitting systems that may not be properly maintained.
- Large centralized systems may also require a disproportionate permitting effort due to environmental regulations and public process requirements invoked with the NPDES (National Pollution Discharge Elimination System) permitting process.

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[43] It should be noted that such studies often have utility to the community beyond their wastewater system design function. Information gathered in such studies is often useful to general planning and environmental resource protection efforts, for instance.

[44] In some cases fees are transfer payments between system owners and local government that have no basis in actual system costs.

11.3.4 Monitoring equipment

Decentralization cost: *Because of the large number of treatment units and effluent discharge points inherent in decentralized systems, capital costs of equipment for monitoring equivalent to that undertaken at centralized wastewater treatment plants would be substantially higher.*

Decentralization consideration: *Depending on the treatment technology chosen, monitoring capital costs per capita may be lower or higher for decentralized systems than for centralized systems.*

Three general types of monitoring for wastewater treatment facilities can be distinguished:

- Monitoring necessary for process control. This includes monitoring of influent flows and constituents and monitoring of conditions at various points in a treatment process, as well as effluent monitoring. Such monitoring allows process adjustments to improve effluent quality and/or reduce treatment costs.
- Monitoring of discharges. Measurement of the volume and pollutant concentrations of effluent is required for all centralized facilities and some decentralized facilities to determine compliance with regulatory standards.
- Monitoring of ambient conditions potentially affected by wastewater discharges. Regulatory agencies often require ambient water quality monitoring for both centralized and decentralized facilities. For the later, this typically takes the form of ground water monitoring wells located downslope of wastewater soil absorption systems, and often upslope as well.

Centralization concentrates discharges into one or a few locations. Decentralization increases, often substantially, the number of discharge points required for a given population. Were decentralized systems required to undertake the same level of monitoring that is required of centralized facilities, the capital and ongoing costs would be prohibitive. (See §11.4.8 for a discussion of operating costs for monitoring.) For this reason, and because the consequences (e.g. public health emergencies) of system failure are smaller for small systems than for large systems (see §14 on reliability), decentralized systems do not have to meet the same monitoring requirements.

For conventional septic systems, rarely is process or discharge monitoring required. In some cases ambient monitoring may be undertaken by a public authority to track conditions over a large area, but rarely (sometimes for large individual systems) is ambient monitoring required of individual septic systems. Thus, a community that chooses individual septic systems over collection and centralized treatment will likely pay far lower monitoring equipment and installation costs, and lower ongoing costs as well.

The situation begins to change once advanced treatment is added to a decentralized scheme, and sometimes for larger onsite or cluster septic systems. In such cases, many health departments and/or environmental agencies require some level of discharge monitoring and often ambient monitoring as well. The costs can be substantial. For instance, in the community of Paradise, California (Pinkham et al. 2004), all systems with a capacity greater than 400 GPD (which includes large households) require three monitoring wells, in accordance with California Regional Water Quality Control Board requirements. One monitoring well is located up-gradient of the soil discharge zone, and two are located down-gradient. The rules require a system owner to have in place a contract for quarterly or semi-annual sampling of total nitrogen and BOD. These requirements are very unpopular. For systems that are not much larger than the threshold size, installation of three wells can cost more than the rest of the wastewater system. Engineers try to design systems below the threshold capacity when possible, but they have little leeway given wastewater design flows required by the town’s rules. In addition, for all systems over 2,000 GPD, monthly influent and effluent samples are required, plus additional monitoring for activated sludge package plants. The capital costs to enable such monitoring are not large (the necessary measures are mainly taken from grab samples from easily accessed points), but the ongoing costs are significant. The costs of monitoring in Paradise probably are toward the high-end of the range for decentralized systems.

11.4 Operation and maintenance costs

Decentralization cost: *Smaller systems lose economies of scale that are possible in wastewater system operation and maintenance.*

Decentralization benefit: *Decentralization resulting in different technology choices may dramatically shift the nature and frequency of required O&M activities, in some cases reducing O&M costs below that of a centralized system serving the same area.*

Comparisons of the operating and maintenance costs of decentralized and centralized systems are difficult to make, as so much is still poorly understood about the long-run performance and the O&M needs for onsite and cluster systems. The “playing field” for comparison is poorly defined and is rarely level. Centralized utilities typically privatize the onsite costs of the system (for example, maintenance and replacement of house laterals). These onsite costs are typically not counted when centralized wastewater facility plans are done, but they are often counted for decentralized facilities. Planners should be certain that onsite capital and O&M costs are included for both centralized and decentralized options when system costs are compared.[45]

Operational requirements (energy, chemicals, labor, etc.) are fairly predictable for systems of all types, though the costs may vary based on exogenous circumstances such as changes in energy prices. Maintenance schedules (replacement of system parts and components), however, are a subject of some disagreement among experts, especially at the decentralized scale. This results from major uncertainties about long-run performance and failure rates (see §14).

In general, it is thought that operating and maintenance costs of conventional treatment plants decrease per capita as number of persons served increases (Hovey et al. 1977; Tihansky 1974). Reasons for economies of scale in O&M include efficiencies in staffing, and bulk purchase of chemicals, replacement parts, and other supplies.

One example of O&M economies of scale for relatively small systems is portrayed graphically in Figure 11-6. The figure is based on five years of operational cost data for rotating biological contactor/reedbed systems and two-stage reedbeds in Belgium (Geenens and Thoeye 2000).

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[45] Note that while lateral maintenance costs are privatized, additional compensating public costs occur. Planning for centralized systems usually assumes private laterals will not be adequately maintained, resulting in infiltration. This necessitates additional wastewater treatment plant capacity (see §11.1.1). Often 50 percent or more of the I/I in centralized systems is due to private laterals.

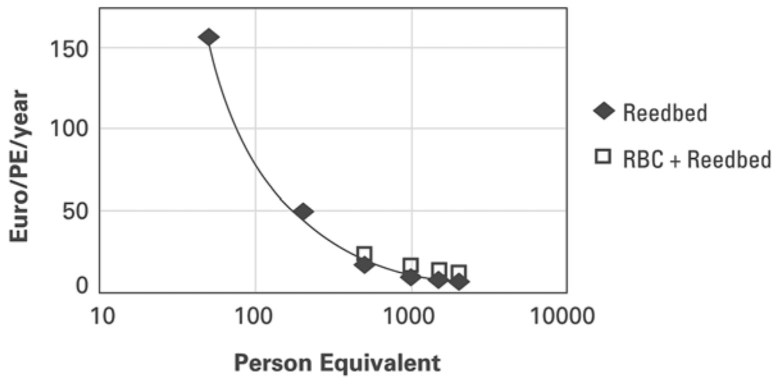

Figure 11-6: O&M Cost Per Person Equivalent for Small Wastewater Treatment Plants in Belgium.
Source: Adapted from Geenens and Thoeye (2000), Figure 7. Used by permission of the copyright holder, the International Water Association.

Some decentralized technologies are significantly different in their treatment plant O&M requirements than others, and than conventional centralized plants. The individual home systems just referred to used the following technologies: aerated lagoon, activated sludge, reedbed, and submerged aerated filter. Had the study evaluated conventional septic systems, costs per PE/year would no doubt have been substantially lower.

Decentralized system O&M costs can be quite low, though experience shows that decentralized systems may show low O&M costs because O&M schedules and expenditures in practice are often woefully inadequate. Collection system O&M is much higher per capita for centralized facilities on conventional gravity sewers than decentralized facilities, due to the costs of sewer inspection, cleaning, and repair.

Operation and maintenance includes many aspects that are essentially predetermined by the type of plant or onsite system and equipment used. For example Bode and Grunebaum (2000) note that for centralized facilities, technology choices can result in a variety of tradeoffs between capital costs and operating costs (quote edited [ ] for grammar and clarity):

- Centralization in the field of sewage treatment by combination or linkup of sewage plants: here the reduced investment costs compared to smaller sewage treatment plants must be set against, among others, the operating cost for the transfer of the wastewaters (sewage maintenance, and, if required, pumping costs), but on the other hand also against decreasing operating cost for the large[r] sewage treatment plant.
- Replacement of bubble aeration by less effective surface aeration in activated sludge plants: here lower investment cost[s] (e.g. for the blower room in the basement otherwise necessary) compare with additional energy cost[s].
- Substituting simultaneous aerobic sludge stabilization for anaerobic [sludge stabilization] processes: here the savings for sludge digestion (minus the investment for the larger aeration tank) have to be compared e.g. with additional energy cost[s] for the biological sewage purification.
- No “in-house” sludge treatment, but contracting out certain tasks by employing the services of another sewage works located not too far away or of external providers: here the savings in investment costs compare with additional transport and co-treatment expenses in the neighborhood [sic; read “neighboring”] plant or by external providers (mobile sludge dewatering, utilization of sludge as material or for incineration).
- No implementation of a more effective sludge dewatering or drying stage: here the lower investment costs compare with an increased expenditure for sludge transport, sludge utilization and/or disposal.

For decentralized systems, capital and operational cost tradeoffs between different technologies are also possible. For instance, constructed wetland systems and waste stabilization lagoons typically have lower operating costs compared to other technologies at similar levels of performance, but require larger spaces, thus increasing total land costs. Higher unit costs of land (e.g., in suburban areas versus rural areas) will make switching from systems with low operational costs but large land requirements to alternatives with lower land requirements but higher operational costs more likely.

For both centralized and decentralized systems, sewer system selection can have an important effect on O&M costs. For instance:

- Conventional gravity sewers may have lower energy costs than pressurized or vacuum sewers (depending upon topography and the need for lift stations).
- Conventional gravity sewers may be more prone to blockages and thus pose higher costs for cleanout than other sewers.
- Pressurized and vacuum sewers have more mechanical parts than gravity sewers. These parts require maintenance and periodic replacement.
- Conventional gravity sewers are more prone to infiltration and inflow, which results in higher hydraulic loads and higher O&M costs at the treatment plant.

It is also important to note that the required level of system performance will often increase O&M costs. For example, Freedman and Stallings modeled how different levels of phosphorus removal systematically increase O&M costs, which include labor, electricity, chemical precipitants, sludge processing, and sludge disposal, for five small wastewater treatment plants in Maine and New Hampshire, as shown in Figure 11-7 (Freedman and Stallings 2000).

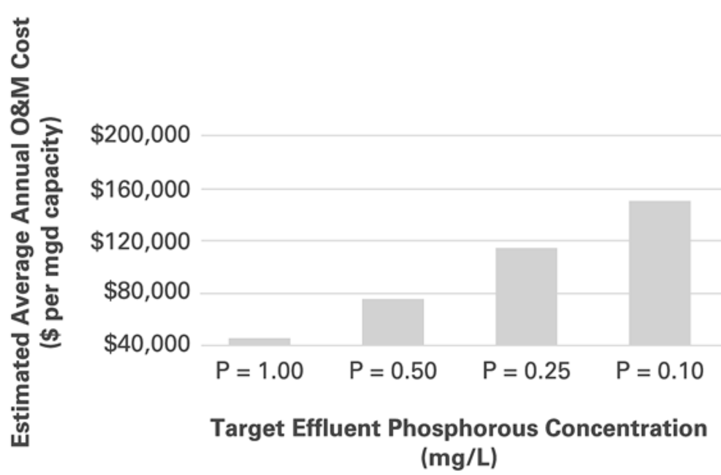

Figure 11-7: Estimated Unit O&M Costs to Achieve Specific Phosphorus Concentrations for 5 Small New England Wastewater Treatment Plants (January 1999 dollars, based on ENR20 cities index = 5,950). *Source: Adapted from Freedman and Stallings (2000), Figure 3. Used by permission of the New England Water Environment Association.*

Bearing in mind that the O&M costs are substantially predetermined by the type of system and required performance levels, each of the following components of O&M is treated in turn in this chapter:

- Labor
- Energy
- Chemicals
- Parts and materials

- Residuals management
- Vehicles and transportation
- Permits and fees
- Monitoring
- Insurance
- Taxes

Record-keeping and reporting are addressed in the chapter on administration and management.

Administration and management are often considered O&M cost components, and could mostly fit under the labor category. They are also often not considered at all. For instance, activities such as billing may be handled within a local government cost center that is apart from the wastewater system cost center. Onsite system inspections may be handled by the building inspector or by a sanitarian at a different level of government; for instance, the county health department. In these and many other cases, differences in administration and management costs between centralized and decentralized alternatives are often not priced when a consultant evaluates the costs of wastewater system options. To clarify the cost implications of administration and management, and because management is such an important topic within the decentralized wastewater field at the current time, administration and management are considered in a separate chapter.

11.4.1 Labor

Decentralization cost: *For a given technology, labor costs exhibit economies of scale; decentralizing that treatment technology will result in increased labor costs per unit of capacity.*

Decentralization consideration: *Decentralization usually results in different technology choices, which may have lower or higher labor costs per unit of capacity across the whole system than a more centralized system would.*

Labor is typically the largest O&M cost component. Labor includes staff of the utility, local government, or other RME that manages a centralized or decentralized system, and it also includes contractors. In a study of 242 wastewater facilities serving 1 to 2,000 people in southeast England, Rowland and Strongman (2000) found that employee labor accounted for 43 percent of total operational expenses, and contractors accounted for 13.9 percent.

For centralized treatment plants, labor requirements are well-known for most processes and equipment, and can be adequately estimated by competent engineers. Labor for effective decentralized system O&M is still a considerable uncertainty in many cases. This is because historically, individuals or firms responsible for decentralized system installation were (and still are) often not the same as those responsible for ongoing operation and maintenance. In fact, too many systems were and are simply neglected once installed, so information on O&M requirements has not been kept up or collected and synthesized. This is beginning to change as the importance of decentralized system O&M to proper performance and reliability becomes widely recognized, and as calls for improved management (oversight to ensure proper O&M occurs) increase from decentralized system professionals and from regulators at many levels of government.

O&M is critical for assuring longevity of onsite wastewater treatment systems. This is especially true for systems that provide higher treatment levels than conventional septic systems. Table 11-5 by Loomis et al. shows some required inspection, operation, and maintenance procedures for innovative onsite wastewater treatment systems and the minimum frequency with which these O&M procedures are needed (Loomis et al. 2002). A case study in Craven Country, North Carolina found that O&M by a trained professional is critical for innovative onsite treatment systems. Also increased site or load complexity (such as increased wastewater strength due to use of highly water-efficient fixtures) increases the O&M requirements (Spooner et al. 1998).

Table 11-5: Required Inspection, Operation and Maintenance Procedures for Innovative Systems

System Component	Required Inspection, Operation and Maintenance Procedure	Frequency
Primary (septic) tank	Check solids level and pump as needed. Check inlet and outlet baffle condition. Look and listen for leaks and tank water-tightness. Hose off effluent/outlet filters.	Yearly
Primary tanks with pumps	Check solids level and pump as needed. Look and listen for leaks and tank water-tightness. Hose off floats, pump, vault screens.	Yearly
Recirculation tanks	Hose off floats, pump, vault screens. Pump tank as needed. Look and listen for leaks and tank watertightness.	Twice per year
Advanced treatment unit / filter	Check distal head pressure on distribution laterals. Flush, snake, and flush again each distribution lateral. Check effluent clarity and odor. Visually check for ponding in or on filter / unit.	Yearly
Electrical	Check operation and function of: UV disinfection unit, programmable timer, float controls, alarms, event counters, run-time meters (record readings). Check electrical junction and panel boxes for watertightness and damage. Secure float cords. Change UV lamps, check for corrosion at lamp socket, and wipe lamp shield.	Yearly
Pump and discharge assembly	In pump discharge assembly – check presence and function of: check valve, weep hole, anti-siphon device. Check that pump is off the bottom of tank. Conduct a pump draw-down test.	Yearly
Shallow narrow pressure dosed drainfield	Visually inspect infiltrative surface in trench and check after a normal dose (dose should freely drain within 5-20 minutes depending on soil type). Check and record distal head pressure on lateral. Flush, snake, and flush again each drainfield lateral.	Yearly

Source: Loomis et al. (2002), Table 4.

Given the deficits in decentralized system O&M cost information noted earlier, what can be said in comparative terms about labor costs across a range of system scale? The following points are notable:

- Much of the cost for centralized system O&M is for the collection system. Conventional gravity sewer maintenance is expensive. For large centralized wastewater systems in the United States, a Water Environment Federation benchmarking study in 1997 found the national average sewer inspection and cleaning labor cost per mile maintained per year was $3,626, plus an average of $1,185 in fringe benefits per mile maintained per year (U.S. Environmental Protection Agency

1999).[46] Decentralized systems that eliminate or use simple, small collection systems may present a significant staffing advantage.

- However, cluster systems using alternative sewers have components that may require more frequent inspection and maintenance (for instance, pumping of septic tanks, servicing of effluent pumps, grinder pumps, and other mechanical components) than conventional sewers (Jones et al. Undated).[47]
- Even so, the low supervisory requirements of some cluster system technologies compared to more complicated systems at conventional centralized activated sludge plants may more than offset any labor cost differences between gravity and alternative sewers. For example, cluster-scale sand filters, constructed wetlands, and some other technologies typically require inspection on a monthly or quarterly basis, with some visits including operational adjustments, while centralized activated sludge plants must be continually observed, or nearly so, with frequent operational adjustments.
- As well, technologies for remote monitoring of wastewater treatment processes are increasing, which in turn allows for significant reductions in routine site inspections (Jesperson 2000; Rowland and Strongman 2000). Technologies for remote control of system operations are also becoming available. Both remote monitoring and remote control technologies are likely to become less expensive over time. This would tend to increase the economic viability of decentralized systems.
- For conventional (activated sludge) treatment plants, Tsagarkis, Mara, and Angelakis (2003) found in a survey of 66 plants in Greece that small installations need more personnel per person served than larger ones. Their study encompassed plants ranging in size from 500 person equivalents (PE) served to over 100,000 PE served.
- More complicated systems (e.g. activated sludge package or centralized plants) require higher levels of operator technical proficiency not often found in rural locations. This in turn requires higher salaries, which may be difficult for small communities to support. When workers acquire the necessary expertise through training and experience, they frequently have the opportunity for higher salaries in nearby cities. Therefore, treatment systems that require larger land areas, but less complex O&M are often attractive for small communities. Such systems minimize the need for process understanding and rely more on the mechanical aptitude of the O&M staff, which in rural settings is often more available. (Jones et al. Undated). Tsagarkis, Mara, and Angelakis (2003) came to a similar conclusion.
- A large under-loaded treatment plant may have higher O&M costs per user than a similar treatment plant operating at design capacity at the same load. This is possible since staff requirements increase partly as a function of design capacity, as well as actual flow. Thus, a larger O&M staff could be needed for a larger under-loaded plant than for a smaller, fully loaded plant at the same load (Pearson and Scherer 1981). (This has important implications for planning an optimal capacity expansion path in growing areas. See §8.1.4 in the financial planning chapter.)

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[46] These figures do not include costs for additional collection system maintenance, such as lift station maintenance. Additional significant sewer line maintenance costs that do not fit easily into the O&M categories of this chapter include hydroflush cleaning services ($512 per mile hydroflushed per year) and television inspection services ($4,600 per mile TV-inspected per year).

[47] On average, any given mile of a conventional gravity sewer is inspected, cleaned, or otherwise maintained on an interval that spans many years. This is in part because sewer authorities rarely have the funds to keep up aggressive maintenance schedules.

11.4.2 Energy

Decentralization cost: *For a given technology, energy use exhibits economies of scale; decentralizing that treatment technology will result in increased energy costs per unit of capacity.*

Decentralization consideration: *Decentralization usually results in different technology choices, which may have lower or higher energy costs per unit of capacity across the whole system than a more centralized system would.*

In general energy is the second largest O&M cost. For centralized plants, energy consumption typically makes up 30 percent of the O&M costs for wastewater treatment (Metcalf & Eddy Inc. et al. 2003). Wastewater systems in the United States consume approximately two percent of the total amount of electricity produced. During the next 20 to 30 years the electricity requirements for wastewater treatment is expected to increase an additional 30 to 40 percent (Metcalf & Eddy Inc. et al. 2003). The increase in energy consumption can be explained by requirements for increasing levels of treatment.

Energy use by decentralized systems is highly variable, depending upon the technology. Some systems (e.g. typical septic systems with gravity distribution of effluent to a soil absorption field) require no energy use, excepting the negligible energy used to pump the septic tank every few years. Others, such as aerobic treatment units, require continuous or long-period energy use, in this case for the blower(s) that aerate the system. Many systems fall in between, requiring relatively small amounts of energy to operate pumps that move wastewater from one compartment of a system to another, or through pressure or vacuum sewers to a cluster treatment system. Typically, obtaining higher performance standards (e.g. nutrient removal) from particular technologies requires greater energy use. However, choosing a different technology—for instance, constructed wetlands or recirculating sand filters instead of aerobic treatment units with biological nitrogen removal—can provide high quality effluent with low energy use, though other tradeoffs such as increased land area requirements are incurred.

For centralized systems the electric motor driven equipment involved in operations include pumps, blowers, mixers, sludge collectors and centrifuges (Metcalf & Eddy Inc. et al. 2003). Activated-sludge aeration uses over half of the energy consumed by a treatment plant (Metcalf & Eddy Inc. et al. 2003). Some plants operate their aeration blower motors constantly at full capacity (Metcalf & Eddy Inc. et al. 2003).

With the increasing costs associated with electrical use, a lot of attention in the wastewater O&M literature is being directed toward energy consumption, particularly for centralized activated sludge systems due to their substantial energy requirements. Various motor management schemes are being analyzed and used, changing the amount of energy consumption. Some plants adjust operation schedules for pumping, aeration, and solids processing according to wastewater load changes, thereby minimizing energy consumption. Furthermore, energy-efficient motors are likely to become more common (Zakkour et al. 2002).

Centralized and decentralized systems are likely to differentially apply equipment and operational changes. For centralized systems, alterations in operation schedules (e.g., adjusting blower cycles) are more likely since it is cheaper to alter operation schedules than it is to retrofit more energy-efficient equipment or to construct new physical facilities using more energy-efficient equipment (Metcalf & Eddy Inc. et al. 2003).

Centralized systems are likely to take advantage of new, more energy-efficient equipment when traditional treatment methods are deemed no longer legally acceptable, requiring a technology change. One such case occurred in Amelia County, Virginia. The state began phasing out traditional pond and lagoon systems, so the wastewater treatment plant in Amelia County constructed a new continuous sequencing batch reactor process—a much more energy-intensive technology. The new plant utilizes programmable logic controls that start and stop aeration equipment as needed to maintain optimal dissolved oxygen levels. This system helps the plant meet strict effluent quality requirements while minimizing energy consumption—the plant use 40 to 45 percent less energy than similar plants with continuous aerator operation (Winfree and Tatum 2000).

The same preference for operational changes (except when regulations force capital investments) may not hold true for decentralized systems since the gross investment costs for decentralized systems are lower. The lower investment costs makes it cheaper to retrofit facilities or construct new facilities that utilize more energy-efficient equipment. This is especially true for systems that have high operational costs. Thus, decentralized systems could be more likely to utilize increasingly energy-efficient equipment. This would help decentralized systems to remain a viable substitute to centralized systems.

11.4.3 Chemicals

Decentralization consideration: *Decreasing treatment plant size for a given technology will tend to lose economies of scale from bulk purchase of chemicals, but many decentralized technologies require no chemicals or less than those required for some centralized systems.*

The literature on O&M costs pertaining to the chemical component is very limited for decentralized systems and somewhat limited for centralized systems. According to some studies completed in Greece for centralized wastewater treatment plants, chemical requirements include: polymers, alum and lime for sludge conditioning, NaOCl, Cl_2, Cl_2O, and O_3 as disinfectants, reagents for labs, etc. (Tsagarakis et al. 2003). The chemical costs component of centralized O&M ranged from 4 percent to 8 percent, depending on the treatment technology (Tsagarakis et al. 2003).

Chemical use for most decentralized systems is minimal. A variety of additives for septic tanks, claiming to improve treatment, are marketed, but most professionals believe these additives are unnecessary (U.S. Environmental Protection Agency 2002c). Typically the only chemicals used for decentralized systems are chlorine disinfectants for systems where treated effluent is used to irrigate land accessible to the public, or is discharged to surface waters (which typically also requires dechlorination chemicals).

11.4.4 Parts and materials

Decentralization consideration: *Decentralized systems may require more or less routine parts and materials replacement than centralized systems serving the same population.*

For non-routine parts and material replacements, constituting system rehabilitation, see §8.7 on depreciation and replacement in the financial planning chapter.

Simple decentralized systems, such as conventional septic systems, rarely require replacement of parts and materials. Somewhat more complex systems may require periodic replacement of such things as filter elements or pumps or motor parts. In general, systems that include mechanical systems or are designed for higher levels of treatment will have greater parts and materials requirements. However, this aspect of O&M cost is rarely large compared to other aspects. For instance, for 242 systems serving 1 to 2,000 people in southeast England, Rowland and Strongman found that materials averaged 8.9 percent of total operational expenditures (Rowland and Strongman 2000). In Tsagarakis et al.'s survey of treatment plants in Greece, parts ranged from 6 to 9 percent of total operational costs, depending on the treatment technology.

11.4.5 Residuals management

Decentralization consideration: *Technologies used for decentralized systems tend to generate lower quantities of biosolids or require less biosolids handling. This may reduce the per capita costs of residuals management.*

Activated sludge treatment plants, the most common technology used in centralized systems, produce large quantities of biosolids. These residuals must be separated from treated effluent, de-watered, and then landfilled, land-applied, or digested through further processes. All of these approaches result in considerable costs, though they do show economies of scale, and digestion produces gas that has an energy value which can be used to offset residuals handling or other costs at the treatment plant. Digestion processes require fairly large volumes to be economically feasible.

In contrast, many decentralized technologies (e.g. anaerobic treatment in septic tanks, biofilters, and wetlands) yield reduced residuals handling problems. Costs may thereby be reduced. However, the trade-offs on a per capita basis between these reduced handling problems and the residuals management economies of scale possible in centralized facilities are not always clear.

11.4.6 Vehicles and transportation

Decentralization cost: *Because decentralized treatment systems are dispersed, they probably require more travel for inspection, operation, and maintenance than more centralized systems.*

Collection systems serving centralized systems are as or more dispersed[48] than decentralized treatment systems. However, visits to dispersed collection system locations are probably less frequent per capita or per connection than visits necessary for proper inspection, operation, and maintenance of treatment units, with the possible exception of conventional septic systems.

There are at least two classes of opportunities to reduce travel costs for decentralized system management and operation:

- Design for low maintenance
- Remote monitoring and control

As an example of the first strategy, consider the Mobile Area Water & Sewer System (MAWSS), which operates the centralized wastewater system in and around the city of Mobile, Alabama (Pinkham et al. 2004). In 1999, MAWSS began building cluster systems, mainly using STEP collection systems, to serve new developments in the rapidly growing exurban area west of Mobile, instead of extending sewers. MAWSS designed its cluster systems to minimize operational and maintenance requirements. Maintenance or repair calls would be disruptive to staff, who were and still are located roughly an hour's drive from the most remote decentralized system. To minimize O&M costs, O&M-related travel, and to ensure system reliability, MAWSS took the following steps regarding the design and construction of cluster systems:

- Septic tanks are sized to require pumping only every three to five years.
- The on-lot system has sufficient capacity to operate normally for 48 hours if a pump fails, allowing ample time for MAWSS personnel to respond.
- Septic tank effluent screens are required. These screens reduce discharge of solids and grease that could clog collection lines and components of the advanced treatment facility. Filtering effluent at

[48] Collection systems are more dispersed to the extent that they cross spaces (parks, lakes, industrial areas, etc.) where few connections (and thus hypothetical treatment nodes) are located.

each connection also allows advanced treatment units to be sized for and operated at a higher hydraulic loading rate.

- Developers must build collection lines and on-lot components to MAWSS specifications.
- Each connection (septic tank and appurtenances) receives a final inspection by MAWSS personnel before start-up.
- The developer must provide a two-year warranty on the collection system.
- Homeowners connected to the cluster systems sign a legal agreement designed to reduce O&M requirements and repair calls. For instance, the homeowner agrees to not install a garbage disposal, and "homeowner further agrees not to dispose of grease or other kitchen waste solids into the sewer or collection system. … Homeowner understands and agrees that damage to the collection system or excessive maintenance caused by homeowner … will be billed to homeowner."
- Each advanced treatment facility has backup power.

As an example of the second strategy, MAWSS has installed Supervisory Control and Data Acquisition (SCADA) systems to allow remote monitoring of the cluster systems.

11.4.7 Permits and fees

Decentralization consideration: *Periodic permit fees and other fees paid to government bodies in order to operate a wastewater system can range from nonexistent to substantial and may or may not be significant on a per capita basis.*

In some jurisdictions, once a homeowner has paid for an initial permit for an onsite system, no ongoing permit fees are required. Other jurisdictions have in place annual or periodic permit fees that may range from a few dollars to several hundred dollars per year. Many jurisdictions will also impose fees on onsite systems for various services needed from time-to-time by a homeowner, such as building clearances, proof of a recent, passed inspection needed for a home sale, onsite system variance applications, etc. Some such fees might be more correctly counted as part of capital costs.

Initial permitting fees for cluster and centralized systems can be substantial, reflecting the costs to local or state agencies of reviewing project designs, inspecting construction, and so on. Ongoing permit fees may be considerably less.

Care is necessary in accounting for fees when comparing the costs of different scale systems. Depending on the cost perspective of the analysis, a fee may be a real cost paid to an outside agency, or simply a transfer payment within the unit of analysis. For instance, if a community is evaluating its wastewater options, it should count as real costs any permits paid to higher level governments. But fees charged to homeowners by the community should not be counted, as they are simply a mechanism to recover costs incurred by the community to run a wastewater system or program. Instead, the costs of running the program should be counted.

11.4.8 Monitoring

Decentralization cost: *Because of the large number of treatment units and effluent discharge points inherent in decentralized systems, costs for ongoing monitoring equivalent to that undertaken at centralized wastewater treatment plants are substantially higher.*

Decentralization consideration: *Depending on the technology chosen, ongoing monitoring costs per capita may be lower or higher for decentralized systems than for centralized systems.*

See §11.3.4 for important comments regarding the nature of monitoring for wastewater systems. Ongoing monitoring costs can be significant for centralized systems, and depend on the type of treatment technology, plant location, federal and state regulations, and other factors.

For conventional septic systems, rarely is process or discharge monitoring required. In some cases ambient monitoring may be undertaken by a public authority to track conditions over a large area, but rarely (sometimes for large individual systems) is ambient monitoring required of individual septic systems. Thus, a community that chooses individual septic systems over collection and centralized treatment will likely pay far lower monitoring costs.

The situation begins to change once advanced treatment is added to a decentralized scheme and sometimes for larger onsite or cluster septic systems. In such cases, many health departments and/or environmental agencies require some level of discharge monitoring and often ambient monitoring as well. The costs can be substantial. For instance, in the community of Paradise, California (Pinkham et al. 2004), all systems with a capacity greater than 400 GPD (which includes large households), in accordance with California Regional Water Quality Control Board requirements, are required to have in place a contract for quarterly or semi-annual sampling of total nitrogen and BOD for two down-gradient and one up-gradient ground water monitoring wells. These tests run $55 (if a well is dry) to $150 per well (if water is encountered) per test period. These requirements are very unpopular. The ongoing costs are onerous. Engineers try to design systems below the threshold capacity when possible, but they have little leeway given wastewater design flows required by the town's rules. In addition, for all systems over 2,000 GPD, monthly influent and effluent samples are required, plus additional monitoring for activated sludge package plants. The costs of this monitoring are included within the monthly fees system owners pay to contractors for O&M, which range from $500 to $1,500. The costs of monitoring in Paradise probably are toward the high-end of the range for decentralized systems.

Monitoring costs can be mitigated by cluster systems. In the community of Lake Elmo, Minnesota, homeowners using two wetlands treatment cluster systems of 45 and 88 units pay only $4.91 and $3.96, respectively, for monitoring, sampling, and reporting (paid within a monthly bill that encompasses other O&M costs as well) (Pinkham et al. 2004).

11.4.9 Insurance

Decentralization consideration: *Insurance to cover the costs of repairing or replacing a failed system or system component would constitute an operating cost if chosen, but is only just beginning to be available to wastewater system owners.*

Liability as a financial risk is discussed in §8.3.2. This risk could be mitigated by insurance. The affect of wastewater system scale on the availability, coverage, and cost of insurance against liability for harm caused to others by a failed system is not clear. This section concerns insurance against the costs of repairing or replacing a system should it fail. If available, the cost of such insurance could be considered an operating cost.

For onsite systems, home insurance policies rarely cover such costs unless, for instance, a truck drives over and crushes a system. Failures due to poor siting, design, technology, installation, or other inadequacies are rarely covered. There is little accountability for system failure under the current system. Attorneys are sometimes hired, and sometimes the homeowner is compensated (Stuth 2002).

Development of insurance programs for the onsite wastewater field has been under discussion in recent years. For instance, Herring (1996) notes that participation of private insurance companies, perhaps through riders to home insurance policies, would not only protect homeowners but would also likely lead to improved management and fewer failures, as private insurers would have incentives to set maintenance standards in order to reduce their losses. In the state of Washington, Bill Stuff has worked for development of insurance in the form of a warranty that homeowners could purchase (Eddy 2001; Stuth 2002). Onsite system designers would be certified by a "pool" organization. They would be expected to properly select the system and to oversee its proper installation, and then would be held accountable for any subsequent failures. The homeowner's cost, paid up-front in a single payment and renewable if a system is properly maintained, would vary depending upon the policy value (the percentage of the original cost that is covered) and rating factors that address the relative failure rates of different technologies and the historical failure rate of the particular designer. The cost could range from under $100 to several hundreds of dollars for high policy values on more expensive systems that are found to be less reliable, or if a poorly rated designer is used. The pool would notify the homeowner of required maintenance and monitoring actions at appropriate intervals. Policies of homeowners that do not have the maintenance or monitoring performed would be canceled.

To date and to the best of the authors' knowledge, no insurance programs for onsite systems have been established. Interest in developing such programs remains high.

In centralized systems, homeowners historically have been responsible for repairs when sewer laterals on their property fail. Occasionally home insurance policies will pay for repairs, but typically only if the lateral is damaged by a third party. The cost for trenching, pipe replacement or repair, backfilling, repairing sidewalks and driveways, and reseeding the disturbed area can easily exceed $3,000. These costs are rarely factored into cost estimates for providing sewer service to an area.

While not yet widespread, in some places insurance to cover these costs is available. For instance, in 1999 the state of Missouri passed legislation that enables municipalities to offer sewer lateral insurance. The city of Kirkwood, in the St. Louis area, has one such program (City of Kirkwood Missouri 2004). Its cost is supported by a mandatory $28 annual charge on homeowners' property tax bills. If a homeowner has a blockage, he must first have the lateral cabled by a private contractor at the homeowner's expense. If cabling does not resolve the problem, the homeowner applies to the city for insurance coverage and makes a $740 deposit. A city contractor performs a video inspection to locate the problem. The homeowner obtains three repair bids from city-approved contractors, and usually must use the lowest cost contractor. Once repairs are completed, the city pays the contractor 80 percent of the cost, and refunds the homeowner any remaining deposit after the homeowner's 20 percent is paid. The homeowner is responsible for any costs that exceed 80 percent plus the deposit.

As for insurance against the costs of repairing failures at centralized treatment plants, communities have various options. They can insure themselves by setting aside contingency and reserve funds (enabled by adequate rates, of course). They can also shift risk to the private sector by entering into insurance-backed service contracts. The contracting company will perform maintenance and replacements it deems necessary to properly maintain a system and prevent failure. If a system does fail, an insurance company that stands behind the contractor will pay the costs of repair or replacement.

In summary, insurance or meaningful warranties covering owners for failures of wastewater systems on their property are rarely available for either decentralized or centralized systems. This may change in time. Communities considering their wastewater system options should: a) factor into their cost estimates the costs of failures of components on private property, b) consider whether warranties or insurance programs are available that could defray those costs, and c) consider whether they should set up their own insurance program to assist homeowners (this would probably only be feasible for large communities). In addition, for cluster scale or centralized treatment plants, communities should consider any options they may have to insure against the costs of failure, and the costs of those options.

11.4.10 Taxes

Decentralization benefit: *To the extent that a sewer system adds to property value, using instead an onsite system results in lower property tax payments.*

Decentralization cost: *In the specific case of ownership of onsite systems by a private responsible management entity, the onsite system becomes a taxable asset, and the taxes become an additional cost in comparison to a publicly owned sewer system.*

Section 10.1 notes evidence that a sewer connection can increase property value relative to onsite wastewater service. In such cases, the difference between taxes paid for a property with a sewer connection and the lower taxes that would be paid for the same property with an onsite system represents a cost for the property owner in a centralized wastewater service scenario, or a benefit (avoided cost) for the owner in an onsite wastewater service scenario.

Governments do not pay taxes to themselves or to other governments. Therefore, government-owned wastewater systems, whether decentralized or centralized, do not pay taxes on the asset value of the system.

However, a private RME may incur a tax liability if it assumes ownership of certain parts of a wastewater system. “Contributions in aid of construction” that are on public or shared property are not subject to taxation. An example of this is where a developer pays for the cost of sewer mains, treatment systems, and wastewater soil absorption fields—all on communal property—and donates these systems to a private RME. However, any parts of the system on private property—including individual onsite systems or STEP system tanks, effluent or grinder pumps, and the lateral to the sewer main—if donated to or purchased by a private RME, are considered taxable assets. This is a strong disincentive for private RMEs to own all portions of a decentralized wastewater system, as in Environmental Protection Agency’s management model level five (see §13). For instance, Tennessee Wastewater Systems, Inc, a privately owned RME regulated as a public utility, which operates over 40 cluster systems in 23 counties in Tennessee, originally planned to own all components of the cluster systems they operate, in order to have complete control over the entire system. They chose not to own components on private property because of this tax liability (Pickney 2004).[49]

11.4.11 Record keeping and reporting

See Chapter 13 on management.

11.5 Putting the pieces together: tradeoffs between economies and diseconomies of scale

Total direct monetary costs for a wastewater system include:

- capital costs, including both treatment and collections systems,
- operating costs, and

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[49] The company instead uses easements recorded in property plat records and clauses in sales contracts between developers and lot buyers, in homeowner association covenants, and in service agreements, to gain full ingress and egress rights to the private properties and exclusive rights to operate and maintain on-lot portions of the system. It does own the shared components of the system—mains, treatment systems, and soil absorption systems.

- management costs.

In this report, management costs are addressed in a separate chapter to highlight their importance. Depending on how a particular wastewater planner parses costs in an integrated wastewater planning effort, management costs may be included as part of operating costs. Communities should be sure management costs are included in one way or another.

Additional direct monetary costs may be incurred if components or facilities are added to take advantage of synergies with other infrastructure; for instance, additional treatment units and distribution systems so that wastewater can be reused as a water supply. Such additions typically also have direct monetary benefits that compensate for some or all of their costs. This additional aspect of integrated wastewater planning is considered in the next chapter.

A final direct monetary cost that should be considered in integrated wastewater planning is the cost of financing. This cost depends on the patterns of capital, operating, and management costs over time, and so can only be evaluated once those patterns have been determined for various wastewater options. Chapter 8 addresses financing issues.[50]

This chapter has addressed capital and operating costs vis-à-vis system scale. The discussions have shown:

- Treatment systems typically show increasing returns to scale (economies of scale).
- Pipe networks typically show decreasing returns to scale (diseconomies of scale).
- Operating costs typically show increasing returns to scale, although technology choices may affect whether centralized or decentralized systems have less expensive operating costs.

This chapter has noted additional cost factors that may be more or less expensive for decentralized systems compared to centralized ones. For instance, these include capital costs for manholes and lift stations, land, planning and engineering, initial permitting, and monitoring equipment.

The various economies and diseconomies of scale of all system components, taken altogether, determine total direct system costs (capital and O&M) across a range of scale. Few rigorous examinations of multiple component economies and diseconomies across a range of system scale and their effects on total system cost are available. In the research for this report, the best example found was the previously mentioned study by Richard Clark (1997). This study and its results will now be further described to illustrate how trade-offs between economies and diseconomies of scale influence total system costs. While this study does not thoroughly address the technologies and costs of decentralized systems, or address alternative sewers, it does reveal a number of general tendencies in the economies and diseconomies of scale of wastewater systems.

Clark's study takes much of its data from Adelaide, Australia, a medium-sized city in a mixed hilly and coastal plain setting. Adelaide is served by four conventional wastewater treatment plants that range in size from 20,000 to 190,000 services (connections) per plant. Clark examined the capital and operating costs of four wastewater system components: treatment plants, sewers (the pipe network, not counting lift stations or other components), pumps (lift stations), and connections (bends and fittings to connect laterals to mains). The data, methods, and key assumptions used for each were as described below. Understanding the details of the methodology is not really necessary to understanding the key points

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50 Readers are reminded that the economics of wastewater choices encompass much more than direct monetary costs and benefits. A full accounting of all costs and benefits created by wastewater systems would address indirect monetary costs such as water treatment costs required when water supplies are contaminated, indirect monetary benefits such as improvements in adjacent property values when better wastewater systems improve water quality in surface waters, non-monetary costs such as odors, and non-monetary benefits such as habitat creation at wastewater treatment wetlands. These sorts of issues are addressed in other chapters of this report.

about economy/diseconomy tradeoffs, but this information is provided here for readers who are interested. Note that the methodology was most robust for sewer capital costs and treatment plant capital and operating costs, which represent the greatest costs, while simpler data and assumptions were used for pumps, connections, and sewer operating costs. Stronger data for pumps, connections, and sewer operating costs would be unlikely to substantially change the overall results.

Treatment plants: Clark obtained capital costs for typical Australian secondary treatment plants from a variety of design sources, as well as costs for onsite and small-scale plants. Costs for very large plants were based on combined replacement cost values for Adelaide's four treatment plants, allocated to each plant using its design capacity and a log-log relationship. A cost curve was then created based on the best-fit relationship between the data points. Clark recognized the cost inputs and effluent quality outputs of the different plants in his database might not all be commensurate, but had insufficient data to make adjustments. Clark assumed a 25-year economic life for treatment plants.

Treatment plant operating costs, like capital costs, were based on data from Australian sources and a best-fit cost curve developed from the data points.

Sewers (pipes only): From South Australia Water (SA Water), Clark obtained historic data and recent tenders to determine the local installed cost per meter for sewer pipes of different diameters, and fitted equations to this data. Using GIS analysis, he determined the number of services upstream of pipes of different sizes for a number of sample locations in an established area of Adelaide. He also used data from SA Water on the number of services in the catchments of a number of larger trunk sewers (some of which would be considered interceptors in U.S. parlance). The GIS and trunk sewer data allowed derivation of an equation for the number of accounts serviced as a function of sewer pipe diameter. Together, these equations allowed derivation of the cost per service per meter of pipe for pipes of different diameter. Clark then created a grid-based pipe network model that allowed accumulation of the number of connections, pipe length, and pipe diameter as the number of cells captured by each "treatment plant" in various scale scenarios increased. Applying the cost data to the network model's determination of pipe lengths and pipe diameter produced figures (a cost curve) for cost per service across a range of scale from 1 to 1,000,000 services.[51] Clark assumed an economic life of 50 years for sewer pipes.

Sewer operating costs were based on an allocation of SA Water's 40 Australian dollars ($A) per year per service cost of operating the entire Adelaide collection system. First, $15/year was allocated to pumping costs based on the calculation described below. The remainder was allocated arbitrarily at $10/service for small sewers and $15/service for connections. No operating costs were allocated to large sewers because Adelaide's collection system operating costs are believed to be mainly for pumping and for removal of blockages, of which 80 percent occur in small mains and connections. Sewer operating costs were assumed to be invariant with scale, excepting zero costs for onsite systems.

Pumps: SA Water data showed that the 301 pumping stations in Adelaide had a replacement value of 47 million Australian dollars. Clark divided this figure by the 390,000 accounts served to determine an average capital cost per service of $121A. Clark assumed pump stations would not exceed 2,500 services in capacity because pump stations in Adelaide are mainly used on smaller sewers in hilly areas, not on larger sewers. He used the $121A/service figure as a maximum cost per service, reached at 2,500 services. Clark assumed an economic life of 15 years for pump stations.

Pump station operating costs were based on an estimate of the energy cost of lifting by 6 meters half the capacity flow of a 300 mm pipe, for all 301 pump stations. This amount was doubled to account

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[51] Clark's model accounted for 150 millimeter (approximately 6 inches) minimum sewer pipe size in Adelaide. All pipes serving less than 320 accounts were assumed to be 150 mm in size.

for maintenance of the stations. The total was divided by 390,000 services in the system, yielding an average cost figure of $15A per service per year. The cost per service across the range of scale was determined using the same assumptions used for pump station capital costs.

Connections: In this study, the capital cost of connections mainly reflects installation costs and the costs of bends and special fittings used to attach the sewer pipe exiting each property to the sewer main in the adjacent street or easement. While the cost of connections may be affected by development density, insufficient data was available to determine a relationship, so Clark used the average cost of $748A per connection as a constant cost for all scales of service greater than 2.5 services per treatment plant. He assumed an economic life of 50 years.

Operating costs for connections were determined using the data and assumptions noted above for sewer pipes. The cost of $15A per service per year was assumed to be invariant with scale, excepting zero costs for onsite systems.

For capital costs, Clark's cost per service results are shown in Figure 11-8. (This figure is based on undiscounted capital costs whereas the next three figures use annual costs, with capital costs annualized at a discount rate of 7 percent and the economic lives noted above). Figure 11-8 shows clear economies of scale in treatment and diseconomies of scale in sewers. Based on Clark's data and assumptions, costs per service of pumps and connections are largely insensitive to the scale of service. Note that the curve showing the economy of scale for treatment is quite steep from 1 to 1,000 services. Heaney et al. (1999, p. 10-8) provide a good summary of the implications of this cost curve:

> The capital cost per service for treatment plants decreases rapidly from over $7,000A to a minimum of around $1,000A at a very large system serving one million customers. However, the unit treatment costs are only about $1,500A per service for 1,000 services and about $1,100A for 10,000 services. Thus, of the total cost savings of about $6,500A per service as treatment goes from one to one million services, $6,000A or over 90 percent of the total potential savings in treatment are achieved at the 1,000 service size.

The economy of scale in treatment is offset by the diseconomy of scale in sewers. Note that the total increase in cost per service from 1 to 1,000,000 services is about $5,000A. Of this, about $3,500A, or about 70 percent, occurs by the time a service scale of 1,000 services is reached.

Figure 11-9 shows annual operating costs per service from Clark's model. Again, substantial economies of scale for treatment occur. Operating costs for sewers, pumps, and connections are largely insensitive to service scale, given Clark's data and assumptions.

Figure 11-10 combines all of Clark's data. It collapses annualized capital costs per service and annual operating costs per service into total annualized costs per service. The middle line shows costs per service at the population density used in Clark's pipe cost model. Note that most of the cost savings occur in going from 1 to 100 services. (Total savings are about $1,000A minus $600A, or $400A. Savings at 100 services are about $300A, or 75 percent of the total savings.)

Figure 11-10 also shows the effect of density of total cost per service, based on sensitivity tests Clark performed in his analysis. Using the density in Clark's original data as an index value of 1, the lower line shows the effect of increasing density by a factor of 5. Recall that higher density results in shorter pipe lengths per service (see §11.2.2). This reduces the diseconomy of scale in pipe network costs. Thus the total cost curve in Figure 11-10 shows greater returns to scale, with the total possible savings now at about $600A per service per year. However, note that the much of the total savings are still captured at relatively low scales—$400A, or 67 percent, at 100 services, and about $500A, or 83 percent, at 1,000 services.

If density *decreases* by a factor of 5 (an index value of 0.2), the effect on total cost per service is shown by the top line in Figure 11-10. Lower density has the effect of increasing per service pipe lengths, which creates a greater diseconomy of scale for the sewer pipe network. In this particular case, a minimum cost per service occurs at about 100 services. After this point, costs per service increase with increasing system scale. The tendency of low density to flatten the cost curve should be considered by wastewater system planners in rural and low-density suburban areas.

Clark also performed a sensitivity test on treatment plant capital cost. Figure 11-11 shows the results. The base case is the middle line, which shows the same values as on Figure 11-10.[52] Increasing treatment plant capital costs shifts the entire curve upward, and has the effect of heightening returns to scale, so the total savings across the range of scale are greater. Even so, for the case in which treatment plant costs increase by a factor of 2, the initial portions of the total cost curve are quite steep, and most of the total possible savings are again captured at 100 to 1,000 services. If treatment plant capital costs are halved, the cost curve becomes quite flat across the full range of scale.

It is very important to note the implications of a flat cost curve. As a curve becomes flat, costs can be said to be invariant with respect to scale across the flat range of the curve. Put another way, one can say that costs are insensitive to scale across a certain range. For instance, the base case shown by the middle curve on Figure 11-10 and Figure 11-11 varies in cost from about $700A per service at 100 services to just over $600A per service at 1,000,000 services, a difference of less than 17 percent. From 500 services (about $650 per service) to 1,000,000 the difference is about 8 percent. When costs are insensitive to scale across a range being considered in an integrated wastewater planning process, then it is fair to say that other, non-cost factors may and perhaps should predominate in decision making. Other chapters of this report highlight many of the possible indirect and non-monetary factors that could be important decision factors.

Finally, it should be said that while Clark's data and the interpretations provided above reflect general tendencies in the interaction of economies and diseconomies of scale, much depends in any wastewater planning process on particular local conditions and cost structures. Location-specific data is always required to make appropriate cost comparisons of centralized and decentralized options.

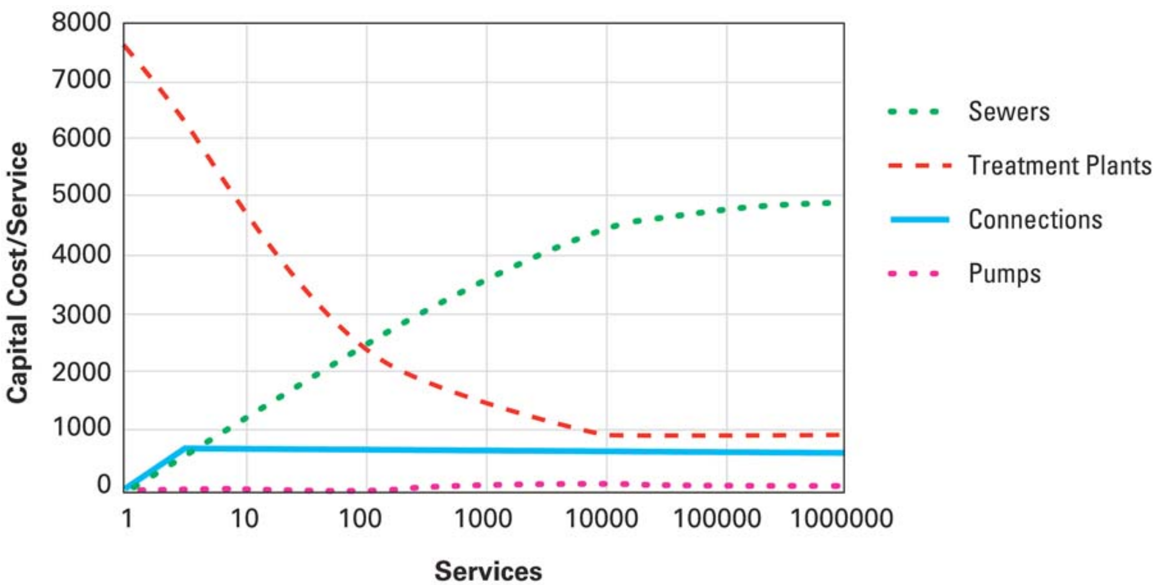

Figure 11-8: Service Scale Versus Capital Costs for Wastewater Systems in Adelaide, Australia. Costs are in 1997 Australian dollars. *Source: Adapted from Clark (1997), Figure 4.1. Courtesy of Richard Clark.*

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52 The numerical range on the vertical axis has increased considerably, so the curve appears somewhat flattened in comparison to the corresponding curve on Figure 11-10.

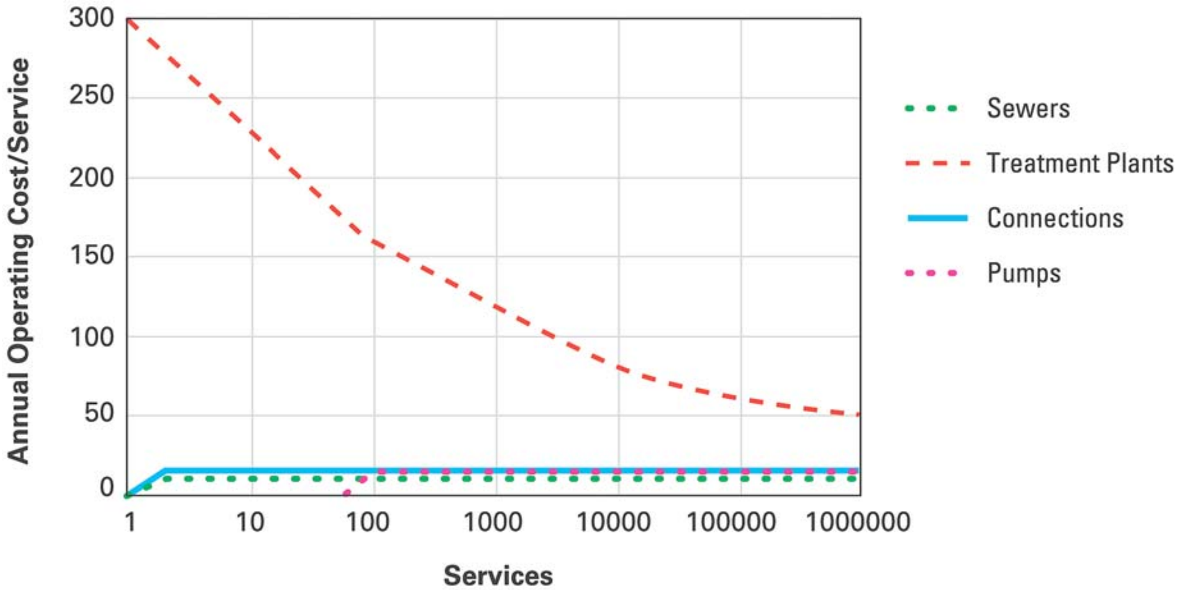

Figure 11-9: Service Scale Versus Operating Costs for Wastewater Systems in Adelaide, Australia. Costs are in 1997 Australian dollars. *Source: Adapted from Clark (1997), Figure 4.2. Courtesy of Richard Clark.*

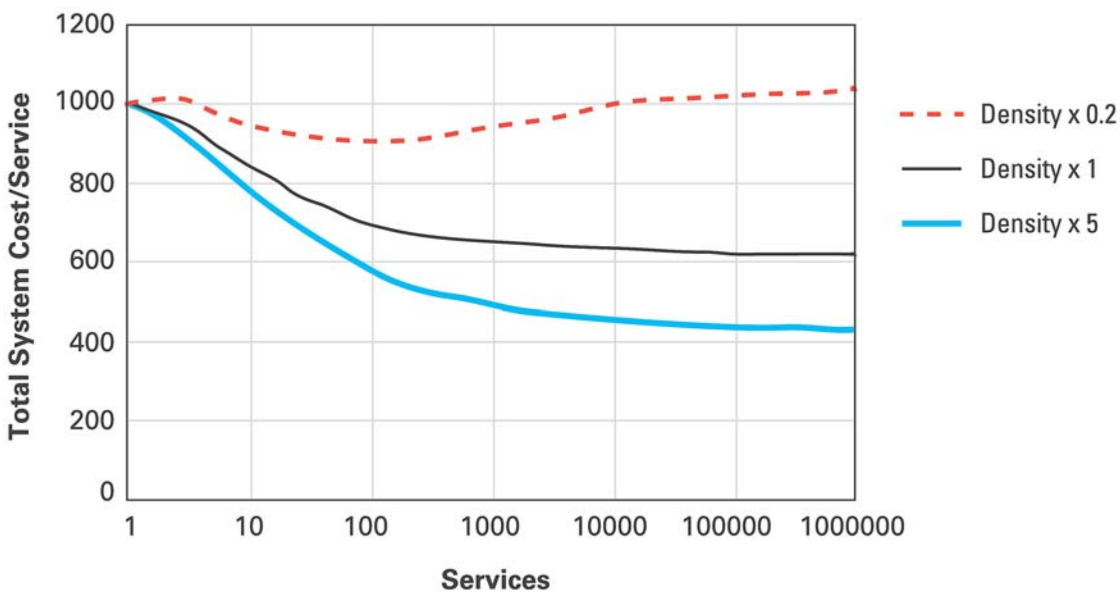

Figure 11-10: Total Annual Costs Per Service, at Varying Population Density, for Wastewater Systems in Adelaide, Australia. Costs are in 1997 Australian dollars. *Source: Adapted from Clark (1997), Figure 4.3a. Courtesy of Richard Clark.*

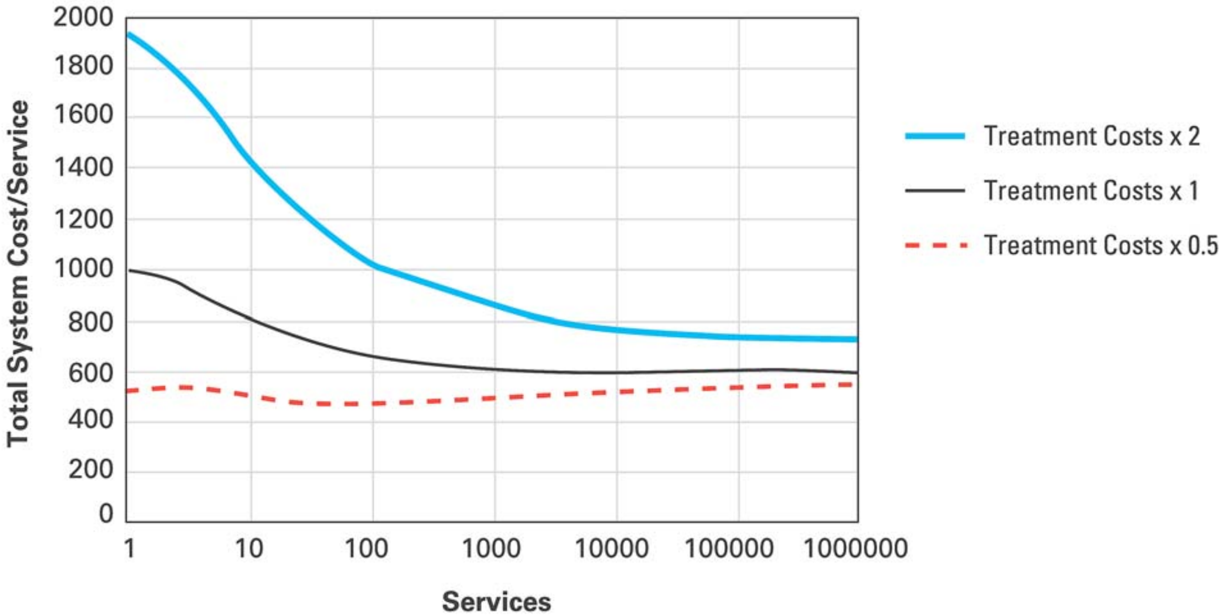

Figure 11-11: Total Annual Costs Per Service, at Varying Treatment Plant Capital Costs, for Wastewater Systems in Adelaide, Australia. Costs are in 1997 Australian dollars. *Source: Adapted from Clark (1997), Figure 4.3b. Courtesy of Richard Clark.*

12 Infrastructure synergies: benefits of integration

This chapter concerns the ways in which wastewater systems can be linked with other infrastructure, or with alternative means (other onsite systems, nonstructural solutions) to achieve the same purposes served by other conventional infrastructure. These opportunities can offset certain costs of wastewater systems.

Clearly, false economies should be avoided. For instance, it is not worth pursuing centralized systems simply to generate biogas or biosolids that can be sold. The costs of systems for capturing/handling/selling these "products" may exceed the revenues, and other systems may avoid those costs altogether. As an example, many decentralized systems generate lower amounts of biosolids per household. "Add-on" systems that provide for cost-effective water reuse, energy generation, and so on should be considered part of the whole-system, lifecycle calculus in comparing wastewater system options.

A useful concept to remember in reading this section is that of "economies of scope." This refers to efficiencies gained when businesses or other institutions provide multiple functions which generate economies of scale in combination (Saal and Parker 2000; Yatchew 2000). For instance, combined water and wastewater utilities, or combined energy, water, and wastewater utilities can economize on administrative labor and sometimes field labor, on vehicles and travel costs, on record-keeping systems and other information technology, and more.

12.1 Water reuse

Decentralization benefit: *By avoiding the capital and operational expenses of large re-distribution networks, decentralized wastewater systems provide opportunities for cost-effective reuse of water at the site and neighborhood scale.*

Decentralization cost: *Onsite and cluster systems do not provide the quantities of water necessary for large water users such as industrial facilities and large landscapes, which in some communities will be the most cost-effective application of wastewater reuse.*

Wastewater is a reliable source of water that is relatively invariant in seasonal availability. It is becoming more important as conventional supply sources are over-burdened, and new ones very expensive to develop. In the future, wastewater will become even more important as a water source, given its reliability, as climate change stresses water supplies.

Wastewater reclamation and reuse is a viable source substitution strategy for communities facing water supply constraints or high costs for new supply. Many nonpotable uses can be supplied by reclaimed water, including landscape irrigation, industrial processes and cooling, construction, vehicle washing and other cleaning, toilet and urinal flushing, fountain supply, and more. Reclaimed water is also used to maintain landscape ponds, aquaculture systems, wetlands, and other environmental amenities and resources. The U.S. EPA (2004) and Asano (1998) provide many water reuse case studies. Water reuse has grown to 358 million gallons per day in California, and 575 MGD in Florida (U.S. Environmental Protection Agency and Camp Dresser & McKee 2004).

Reuse can be accomplished by centralized treatment and a second, non-potable distribution system for treated effluent return to points of use, or by onsite or cluster-scale reuse systems that avoid the expense of dual water supply piping.[53] The relative suitability of onsite, cluster, and centralized systems in

[53] Treatment of wastewater to potable standards is possible and may even be cost-effective in some water-short areas. Direct potable reuse would use the same potable water distribution system used for first-use water, and

providing source substitution and environment benefits at least cost depends greatly on specific local conditions. Facility planning processes should incorporate reuse configurations, costs, and benefits, but typically do not.

12.1.1 Value of reusing water in onsite and cluster systems

Indirect water reuse occurs in many onsite and cluster wastewater systems. Most such systems dispose of treated wastewater through a wastewater soil absorption field. Often the water, further treated by passage through the soil and subsoil, finds its ways to ground water aquifers that are used as potable water supplies. In this respect, decentralized wastewater systems with soil discharge differ little from centralized wastewater systems that discharge to surface waters that are used as water supplies (e.g., via downstream water supply intakes). Both represent “unplanned indirect reuse” (Clerico 1999). This section is concerned instead with planned, direct reuse, in which treated effluent is recycled directly to a point of use.

Many decentralized wastewater treatment systems provide potential for direct reuse of water at the individual property or neighborhood scale. At this scale, while graywater reuse[54] is certainly much more common than blackwater reuse at this time, advanced decentralized wastewater treatment systems make blackwater[55] reuse a viable opportunity under proper conditions. Typically, treated effluent is used to irrigate vegetation or support landscape water features such as ponds and wetlands. Doing so may involve various monetary costs, and provides a variety of monetary and non-monetary benefits.

Costs in addition to the decentralized treatment system may include storage tanks or ponds; distribution lines; drip emitters, soaker hoses, sprinkler heads, or other irrigation devices; pumps; permits; disinfection; signs; fencing; operational costs such as pumping energy; cleaning and other maintenance of system components; and monitoring and supervision. These costs are largely well understood and easily quantified by engineers familiar with the relevant technologies and local conditions. Frequently these costs can be co-mingled with, or are already borne by other systems; for instance, irrigation systems supplied by conventional water sources, rainwater collection, or stormwater detention. For some decentralized wastewater systems, effluent dispersal via irrigation may be integral to final treatment or effluent disposal and thus a core cost rather than an add-on cost.

Benefits may include:

- avoided purchases of water from local water providers;
- avoided pumping costs for self-supplied systems;
- avoided water treatment costs for self-supplied systems;
- development of a higher-value landscape where water is costly or in short supply, with concomitant increases in property values plus intangible benefits to property owners;
- maintenance of landscape during drought periods when irrigation with first-use water is restricted, including avoided costs of replacing plantings that would otherwise die; and

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thereby would eliminate the costs of a second, non-potable distribution system. However, culturally and politically, direct potable reuse is probably many years off.

54 Graywater is water from bathrooms and washing machines, but not toilets. Kitchen sink water is also usually excluded from graywater systems because of the solids and grease it often carries. Noah (2001) provides a good recent summary of the status of onsite graywater reuse in the U.S.

55 Blackwater usually refers to all wastewater generated by a house or other facility, including both graywater and toilet water. In some cases, such as where a graywater system is in use, blackwater refers to only to toilet and other wastewater not captured separately as graywater.

- fire-fighting supply for systems with storage capacity, which may lead to reduced fire insurance premiums.

Current understandings of and approaches to valuing each of these potential benefits range from straightforward to hazy. For instance, avoided water supply costs are easily quantified for local conditions. Some other benefits are harder to quantify and rarely evaluated.

A generalized assessment of the magnitude of the water supply benefit is useful here to illustrate a benefit stream that can be monetized to help offset the costs of decentralized wastewater treatment systems. For example, the value to users of water supplied by local water systems depends on the price of the water and the portion of the wastewater effluent that can be usefully reused, and thereby substituted for first-use water. Nationally, the median retail price of water is $2.10 per thousand gallons (Raftelis Financial Consulting 1998). Indoor water use averages 69 gallons per capita per day in single-family homes (Mayer et al. 1999). Assuming 3 persons per household, no treatment loss, and use of 100 percent of the effluent for one-third of the year (landscape water use equals or exceeds inside use in season in many parts of the country), the annual value of avoided water purchases per home is $52. The present value of these savings across a 20-year "project lifetime" using a 5 percent discount rate is $648.

Electricity costs for residential ground water wells are typically less. For a hypothetical home system pumping against 180 feet of head with a properly-sized, efficient pump at national average electricity prices, electricity would cost about $0.54 per thousand gallons (McCray 2000). Using the same household size and reuse assumptions as above, the value of reuse water would be about $14 annually, or $174 capitalized.

These average values are not impressive, but the potential savings can be considerably higher in many situations; e.g., higher water or electricity prices, greater depth to ground water, larger households or cluster systems, greater irrigation requirements. For instance, 25 percent of U.S. community water systems serving less than 10,000 persons charge $4.00 or more per thousand gallons on residential water accounts (Shanaghan 2000). Assuming this water rate, 4 persons per household, no treatment loss, and use of 100 percent of the effluent for one-half of the year, annual water savings would amount to $201, and the capitalized value across 20 years at a 5 percent discount rate is $2,505.

It is important to note that price does not always indicate value. In many water systems water prices are subsidized from other revenue sources or may be based on incomplete cost accounting; for instance, by not including depreciation of assets. In many places, the avoided-cost value of reuse water is likely to increase with time, as utilities increase prices to cover currently unmet replacement and improvement needs.

Most importantly, in any water system where demand is projected to overshoot supply within the lifetime of a potential reuse project, the social value of the water reused is not the current price of water, but the marginal cost per gallon of the next water project. This value can often far exceed the current price of water.

12.1.2 Examples of small-scale reuse

Interest in smaller-scale systems for wastewater treatment and reuse is increasing. Factors probably include increasing recognition of the cost inefficiencies of collecting wastewater and then redistributing treated effluent back out to points of reuse, and the idea that smaller-scale and integrated urban water systems may have advantages for environmental and economic sustainability. As well, many large-scale reuse schemes have failed to meet expectations. As of 1996, of 38 large projects that received state financial assistance in California, two-thirds of the projects were delivering less than 75 percent of the expected water (Mills and Asano 1996). In addition to institutional issues dealing with permitting and with cooperation between water and wastewater authorities, a major reason for the reduced deliveries was incomplete or overoptimistic analysis of the market for large amounts of treated wastewater, and related failures to secure customers.

Perhaps the most common application of decentralized systems for water reuse is for landscape irrigation. For instance, the use of drip irrigation lines as an effluent dispersal technology provides opportunities to irrigate landscape that offers numerous advantages. Drip lines allow great flexibility in the placement of the dispersal system, and because they are a subsurface system, they avoid the public health risks and additional costs of surface spray irrigation systems.

Water reuse systems in Japan focuses on urban reuse, including fairly small scale systems, because urban uses can afford higher costs for reclaimed water in the face of substantial water supply constraints in many areas (Asano 2002, p. 31). Uses include toilet flushing in high-rise buildings, industrial reuse, and stream flow augmentation for urban amenities. In some cities, reuse for toilet flushing is mandated in buildings over a certain size (typically 3,000 – 5,000 square meters). Over 1,475 individual building or block-scale wastewater treatment and reuse systems for toilet flushing have been built (Ogoshi et al. 2001).

Reuse of treated effluent for toilet flushing also occurs in the U.S., and is likely to increase in coming years. The community of Tusayan, Arizona, an enclave with about 600 residents and 1,050 hotel rooms at the southern gateway to the Grand Canyon National Park, redistributes tertiary treated effluent from a community wastewater treatment plant to the hotels and other commercial establishments for toilet flushing and a limited amount of landscape irrigation (there is little landscaping in this arid, water-short community). The plant uses extended aeration/denitrification activated sludge basins, and a sand filter tertiary treatment unit plus ultraviolet disinfection to finish the 46 percent of the annual wastewater flow that is reused in the community. Reuse ranges from 22,000 GPD in the low month of December to 112,000 GPD in the high month of July. Forty percent of Tusayan’s total water demand is met with this reclaimed water system (Pinkham and Davis 2002).

In the northeastern U.S., Applied Water Management, a private water/wastewater utility that operates many cluster-scale wastewater systems, provides decentralized wastewater treatment and reuse for toilet flushing. In 1999 it had 16 systems that reused treated wastewater for toilet flushing in shopping centers, individual retail stores, office complexes, a school, a manufacturing plant, and a baseball stadium (Clerico 1999).

In addition to choosing decentralized technologies in new development to provide for efficient reuse, a variety of advanced decentralized technologies can be retrofit into areas already served by conventional collection systems. A promising approach is a practice the Australians call “sewer mining” (Butler and MacCormick 1996) and one that parallels the growing electric power industry practice of “local integrated resources planning,” or LIRP, which identifies “hot spots” in the power distribution system and typically finds that small-scale technologies are most cost-effective in addressing the local needs. In a typical sewer mining scheme, an advanced wastewater treatment unit is located in close proximity to an existing sewer line and a point of non-potable water demand. Wastewater is withdrawn from the sewer, treated, and sent to the reuse point through a short distribution line, saving on the capital and operating (pumping) costs of a longer line from a larger, downstream treatment plant. Sewer mining is also known as “scalping” and “satellite treatment” in the U.S.

Within existing urbanized sewer systems, there may be opportunities to develop new satellite treatment facilities that have the benefits of reducing over-capacity in sewer lines and which reduce point-source discharges from existing treatment plants. In Mobile, Alabama, a national demonstration project is now underway that involves removal of wastewater from an existing sewer line, treatment in several parallel cluster-size filter units, and reuse to irrigate a rehabilitated city park. (Pinkham et al. 2004)

Butler (1996) points out that sewer mining makes economic sense because treatment units add value to wastewater, while pipe, storage, and disposal infrastructure does not. Decentralization of treatment converts non-value adding infrastructure investments into value-adding treatment investments, allowing offset of any lost economies of scale that would be obtained at a larger, centralized plant.

A wide variety of technologies for satellite treatment systems are available that meet requirements for placement in urban neighborhoods: high treatment levels, low footprint and visual impact, and low staffing requirements (Sandino 2002). It should be noted that the configuration and declining cost of some advanced technologies for wastewater treatment are favorable for small-scale systems. Fane and Fane (2004) note that installed costs of some membrane technologies have dropped by a factor of 30 since 1990, and may see additional cost reductions. They also point out that membrane technology is modular, allowing plant sizes from single dwellings to suburban scale; they believe overall system economics will favor cluster-scale plants.

12.1.3 Higher volume reuse

Centralization can provide the volumes of water necessary for certain types of reuse. Where the point of use is close to the treatment facility, such uses can be extremely cost-effective, both for the wastewater facility that can save on discharge costs, and for the user who can obtain necessary volumes, often at less cost than using conventional water supplies. Agricultural irrigation and urban landscape reuse are the two largest volume uses of treated wastewater from centralized facilities (Metcalf & Eddy Inc. et al. 2003, p. 1351). Habitat creation and support is another important use for reclaimed wastewater. Following are some examples of additional uses where large volumes of treated wastewater are required:

- The City of Harlingen, Texas developed an industrial park but recognized that water supply in south Texas was an impediment to recruiting industry. Fruit of the Loom Corporation expressed interest but needed over 1,800 acre-feet per year of high quality water. The city improved wastewater treatment at its central plant—this included the addition of reverse osmosis—and succeeded in recruiting Fruit of the Loom, creating over 2,000 new jobs. Funding for the project, because of its economic development aspect, included grants from the U.S. Economic Development Administration and the Texas Department of Commerce (Filteau et al. 1995).
- San Diego, California has developed the "Water for Industry" reuse project. An early application has demonstrated the economic feasibility and level of reliability necessary to produce very high quality industrial process water for Toppan Electronics, a circuit board manufacturing plant (Gagliardo et al. 2002).
- St. Petersburg, Florida has a dual distribution system that provides reclaimed water on a widespread basis. Uses include over 10,000 residential lawns as well as large landscapes such as schools, parks, and golf courses. Total use is now over 36 MGD (City of St. Petersburg Florida 2004). Reclaimed water use has allowed the city to keep potable water use steady since the late 1970s, despite substantial growth (U.S. Environmental Protection Agency and Camp Dresser & McKee 2004).
- Wastewater effluent can be an important resource for electric power generation plant cooling water, providing a win-win solution: the power company obtains a cheap source of water and the wastewater provider saves on disposal costs, as most of the water is evaporated (Gildan 2002). A project between the City of Redlands, California and Mountainview Power Company for a 1,056 megawatt power plant requiring nearly seven million gallons per day of water is one example (Headrick et al. 2002).
- In Columbia, Missouri, a regional wastewater treatment plant was approaching capacity and required upgrading to a higher treatment level. The city choose to build a constructed wetland as part of the upgrade, and provided its effluent to a 3,600-acre formerly farmed area that was being restored to wetlands by the Missouri Department of Conservation. The wastewater effluent provided a steady source of water necessary for creation of the Eagle Bluffs Wildlife Area (Brunner and Kadlec 1993).
- The City of Phoenix, Arizona will provide water from its 150 MGD 91st Avenue Wastewater Treatment Plant to the Tres Rios Project, an ambitious effort to restore riparian and wetland habitats

at the convergence of the Salt, Gila, and Agua Fria Rivers that have been lost due to water resource development in the region. Ultimately the project is planned to restore an area eight miles long and one mile wide (Gritzuk et al. 2001).

- The Town of Gilbert, Arizona, a booming suburb of Phoenix, uses percolation ponds to recharge aquifers with treated wastewater effluent. The ponds have been modified to provide wildlife habitat and passive recreation and educational opportunities in a 120-acre area. The project has contributed to a rise in the level of the previously declining regional aquifer and provided valuable riparian and wetland habitat restoration (Rall 2001).
- Wastewater effluent has been used for aquaculture—fish farming—in Arcata, California and other locations.

12.1.4 Optimum scale for wastewater reuse

The economics of reuse are highly dependent upon the spatial configuration and volumes produced/needed by wastewater sources and water users, effluent quality requirements, available technologies, and other factors. For instance, to service larger users, the optimum scale depends on the volumes required and the location of the demand within the "sewershed" and relative to a centralized treatment plant. Several examples indicate some of the factors affecting the economic comparison of more and less centralized alternatives.

Hamilton (2004) presents a cost comparison for a hypothetical Colorado community (but based on an existing reuse program), in which non-potable water demands are located in the lower, mid, and upper portions of a watershed. He compares a 6.0 MGD treatment facility and a distribution system to return treated effluent back up the watershed with three 2.0 MGD facilities located near the points of reuse. The economy of scale for the larger central facility results in lower capital costs than for the three distributed treatment facility systems. But this savings is offset by the higher cost of the effluent water distribution system and the higher energy cost associated with pumping reclaimed water for the centralized system. Hamilton also notes, but does not price, the fact that the distributed scheme results in lower disruption to the urban area for construction of the effluent distribution system. He finds that the total present worth for the central and distributed alternatives is $34.3 million and $31.5 million respectively. Hamilton notes that the economics of reuse will be highly dependent on local circumstances and changes in the economic parameters. For instance, the total present worth could be effected by various factors including (Hamilton 2004):

- *Higher interest rates.* An interest rate increase would favor distributed systems because the present worth of the capital cost is highly dependent of the discounted value of the salvage value.
- *More dense irrigation.* A community with densely located irrigation might favor centralized treatment. Distributed systems lose their cost advantage as the amount and compactness of the irrigable area increases.
- *Less vertical gradient in watershed.* Centralized treatment systems are more appropriate in flatter, less steep watershed that require less pumping to get water from the downstream wastewater treatment plant to the upper headwaters.
- *Lower membrane prices*. Arguably the single most important cost in a distributed system is that of an MBR [Membrane Bioreactor] reactor's membrane. As more vendors enter the market and manufacturing production capability is increased, the price for membranes is expected to drop, an obvious benefit for distributed systems.
- *Urbanization of watershed.* Urban watersheds favor distributed systems because they significantly reduce disruption caused by water line construction (Hamilton 2004).

Rimer, Sandino, and Bosch (2004) prepared a similar comparison of expanding a traditional water reclamation versus installing three satellite water reclamation facilities (SWRFs) close to reclaimed water users. They found the SWRF alternative had a total present value cost $2.4 million dollars less than the centralized plant expansion. Ease of operation, system reliability, ease of implementation, and aesthetic considerations were also compared:

- The traditional system only has one treatment plant, providing for easy operation and maintenance. However, the SWRFs are self-contained, require little operator attention, and are automated so operation would not be much more difficult.
- The SWRF technology was judged to be more reliable. This is because: a) failure to meet effluent standards at the central plant exposes all reclaimed water customers to sub-standard water, b) the SWRF technology yields a higher quality effluent, which means that any deviation from the expected performance would be less likely to exceed effluent standards.
- For each SWRF to be implemented, mitigation efforts for noise, odor, and other nuisances would be required to meet concerns of SWRF neighbors. Expansion of the traditional system at an existing site would be easier to implement.
- From aesthetic perspectives the expansion of the traditional system is only slightly more favorable as the site is in an outlying area already impacted by the existing plant. But the SWRFs could be easily enclosed in a building to match the surrounding neighborhood.

Based on the market and non-market valuation of each alternative, the authors concluded the SWRF point-of-sale facility concept is a viable alternative (Rimer et al. 2004).

Sheikh et al. (2002) evaluated a range of options to expand wastewater reuse in the Marin (California) Municipal Water District. These included small-scale satellite treatment plants (sewer mining), salt separation from wastewater at the central treatment plant (necessitated because of saltwater infiltration into sewers), residential graywater systems, and seawater desalination as an alternative to wastewater reuse. Satellite plants were the least expensive option, at a present worth cost of slightly over $2,000 per acre-foot, with the exception of seawater desalination, at just over $1,500 per acre-foot. Residential graywater reuse was among the most expensive options.

In terms of even more finely decentralized reuse systems that make treated wastewater widely available within a service area, the economics of centralized treatment and redistribution of treated effluent vs. decentralized treatment and reuse basically boil down to economies of scale in treatment unit capital and O&M costs vs. diseconomies of scale in wastewater collection *and* non-potable water distribution. Collection and a “dual distribution” system suffers from a “double penalty” in the diseconomies of pipe networks. Such systems, however, have been built in a number of cities (Okun 1997), of which St. Petersburg, Florida is perhaps the best-known example.

Several studies in Australia have shown that fairly small-scale decentralized wastewater treatment and reuse systems may be more economical than large-scale dual distribution schemes. These studies are discussed below.

A study by Richard Clark of the economics of scale for water-related systems in Adelaide, a medium-sized city in South Australia, showed that small-scale systems, averaging perhaps 2,500 connections per wastewater treatment plant, are likely to be cost competitive with much larger plants on the basis of whole system analysis of the wastewater system, and more competitive if the wastewater system is designed to realize synergies with localized stormwater treatment and local reuse of treated sanitary or storm sewer water (Clark 1997; Clark et al. 1997). See the capital and O&M cost chapter for additional information on this study.

A number of isolated small communities in Australia are finding onsite system discharges to be causing environmental problems. This may require sewerage schemes to transport wastewater to regional treatment plants at a high cost, spanning from $20,000 to $40,000 Australian dollars per home (Gray and Booker 2003). At the same time, the cost for delivered potable water has also increased substantially in many communities. Gray and Booker estimate the economic cost of alternative systems to see if discharge nutrient levels can be reduced at lower cost than removing the wastewater to remote sites. In addition, Booker further estimates the economic cost savings of recycling wastewater to delivered potable water.

Gray and Booker consider six alternative scenarios for a hypothetical community. The community has 10,000 people in 4,000 households at a density of 16 houses per hectare. It is currently on septic systems but could be served by a regional treatment plant 20 kilometers away, or by several scenarios for treatment at a local plant 1 kilometer away. The full set of scenarios is as follows: (scenario 1) the sewerage is transported to a large regional treatment plant 20 kilometers away; (scenario 2) a local wastewater treatment system collects all the wastewater; (scenario 3) only black water is collected and treated by a small local treatment plant; (scenario 4) graywater and black water are transported separately and treated separately at a local treatment plant; (scenario 5) is the same as scenario 4 except the flows of gray and black water use the same distribution system at different times; (scenario 6) is the baseline where each household uses a septic tank[56].

Table 12-1 and Table 12-2 summarize the capital costs for each alternative and the nutrient flows to the environment for each alternative. Table 12-1 shows localized sewerage treatment systems are all cheaper than transporting the wastewater to a treatment plant 20 kilometers away. Table 12-2 then shows all alternatives to the septic tanks discharge fewer nutrients to the environment, including scenario 3 which releases graywater directly to the environment. Gray and Booker's estimates show there are lower cost alternatives to regionalized sewerage schemes for fringe urban communities that currently use septic tanks—alternatives which can remove more than 90 percent of the nutrients prior to discharge to the environment, and some of which provide treated wastewater for reuse (Gray and Booker 2003).

Table 12-1: Capital Costs for Alternative Treatment Scenarios for a Hypothetical Australian Community of 10,000

Scenario	Capital costs (1,000s of Australian dollars)			Cost per household (1,000s of Australian dollars)
	Treatment	Distribution	Total	
1. Conventional sewage treatment — Sewage connected to regional sewerage system 20 km away.	6,300	18,300	24,600	6,150
2. Conventional sewage treatment — local treatment.	11,800	10,000	21,800	5,450
3. Local blackwater treatment.	4,900	4,400	9,300	2,325
4. Local blackwater and graywater treatment with each collected using separate pipes. *— including graywater reuse*	8,600	14,400 *+ 3,400*	23,000 *25,400*	5,750 *6,600*
5. Local blackwater and graywater treatment with scheduling of flows in same collection system. *— including graywater reuse*	8,600	10,000 *+ 3,400*	18,600 *22,000*	4,650 *5,500*
6. Septic tanks (no effective removal of N or P).	—	—	—	—
Source: Gray and Booker (2003), Table 3.				

56 The cost for septic tanks was not included as all households are assumed to have them.

Table 12-2: Nutrient Flows to the Environment for Alternative Treatment Scenarios for a Hypothetical Australian Community of 10,000

Scenario	Total nitrogen (kg/year)	Total phosphorous (kg/year)	Pathogens
1. Conventional sewage treatment — Sewage connected to regional sewerage system 20 km away.	2,300	230	low
2. Conventional sewage treatment (local sewerage treatment plant).	2,300	230	low
3. Local blackwater treatment			
Blackwater discharge	370	37	low
Graywater to seepage	4,200	810	moderate
Total	*4,570*	*847*	
4. Local blackwater and graywater treatment with each collected in separate pipes.	2,300	230	low
— *including* graywater *reuse*	*4,200*	*130*	
5. Local blackwater and graywater treatment with scheduling of flows in same collection system.	2,300	230	low
— *including* graywater *reuse*	*4,200*	*130*	
6. Septic tanks (no effective removal of N or P).	54,000	6,500	high
Source: Gray and Booker (2003), Table 4.			

In a separate study, Booker (1999) also considers five graywater reuse alternative scenarios, to estimate the cost benefit of the reduction in potable water demand by recycling graywater for toilet, laundry, and garden watering across a range of scale from 12 to 120,000 households. His five graywater reuse scenarios are: (scenario 1) graywater collection pipe in a separate trench to the reclaimed water distribution system with graywater treatment by chemical coagulation and sedimentation followed by sand filtration and UV disinfection; (scenario 2) same as scenario 1, except graywater treatment is by screening followed by micro-filtration and UV disinfection; (scenario 3) same as scenario 1, except the graywater collection and reclaimed distribution system pipe are in the same trench; (scenario 4) same as scenario 3, except household services were increased from 4 to 12; and (scenario 5) same as scenario 4, except the treatment process for 12 and 120 household connections was membrane micro-filtration and for larger household connections the treatment process used chemical coagulation and sand filtration.

Figure 12-1 summarizes Booker's total cost estimates for the five graywater scenarios for various numbers of connections. This figure clearly shows the optimal size graywater recycling system is for more decentralized systems ranging from 1,200 to 12,000 household connections with a flat capital cost to scale curve. This flat curve indicates low sensitivity to size for systems within this range. For larger systems the cost of transport raised the total cost, and for smaller than 1,200 household connections treatment costs dominate the total cost for the system. The minimum estimated cost for water produced by a reclaimed graywater system is $0.5/m^3, in Australian dollars, which is cheaper than current Australian prices for potable water (e.g. $0.70 to $0.80/m3 in Australian dollars for homes in Melbourne, according to Booker 1999). Besides this direct economic incentive the reclaimed water reduces the demand on potable water supplies and reduces wastewater flows to sewage treatment plants (Gray and Booker 2003). The cost of water produced at a scale of 120 homes is about twice the cost at 1,200 homes, but could still be economic in areas with scarce water and high costs to develop new supplies. However, the steep rise in the cost of water as scale decreases to 12 homes indicates that a scale of service much below 100 homes may not be economic. The optimum scale will of course vary with local conditions and design requirements.

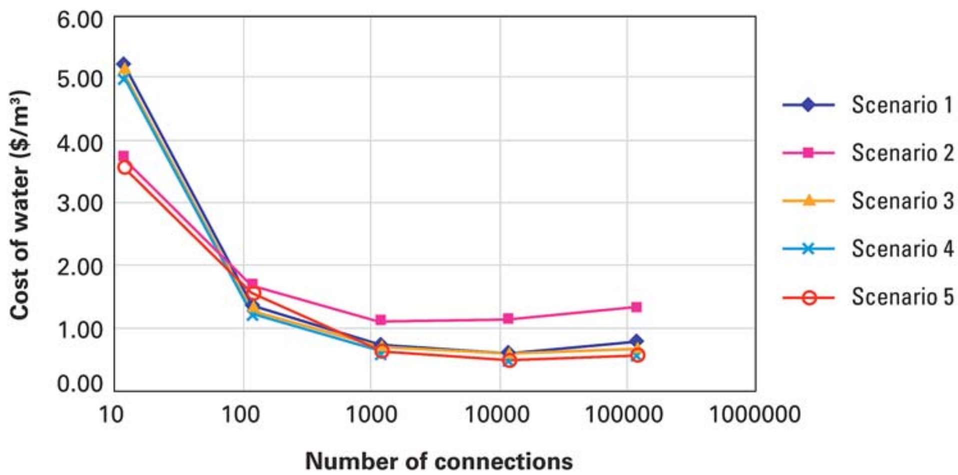

Figure 12-1: Total Cost of Water by Scale of Service for 5 Hypothetical Graywater Reuse Options.
Source: Adapted from Booker (1999), Figure 11. Courtesy of the Commonwealth Scientific and Industrial Research Organization (CSIRO).

12.2 Stormwater management

Decentralization consideration: *Integration of wastewater and stormwater systems can be considered, under particular conditions, across a range of scale.*

Another area of possible integration between wastewater systems and other infrastructure is to combine portions of wastewater and stormwater systems.[57] Constructed wetlands have been used for exactly this purpose, for example, in Monticello, Florida. This north Florida community of 10,000 needed to provide tertiary wastewater treatment at its central plant prior to discharge to surface water, and chose a system that utilized overland flow and a constructed tertiary treatment wetland. It sized the wetland to simultaneously process stormwater flows from a 1,328 acre watershed (Leszczynska and Dzurik 1994). Such a system is probably most appropriate for fairly centralized systems, and requires ample land. Similar systems may have higher potential in developing countries (Iwugo et al. 2002). However, Clark (1997; 1997) argues that an integrated wastewater and stormwater system, which he proposes would include water storage through aquifer storage and recharge (ASR) would be most efficient at a fairly distributed scale (see Figure 12-2 for the full concept):

> Both the cost efficient storage and recovery of water from aquifers and the deployment of artificial wetlands to provide multiple benefits require a spatially distributed approach to water systems design for the following reasons:
>
> - Bores used for injection and recovery of water in aquifers must be disturbed to avoid mutual hydraulic interference and loss of efficiency;
> - Flood peak and pollution mitigation schemes are most effective when operating close to the areas of flow generation and pollution entrainment;

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[57] Integrated systems are not the same as combined sewer systems. The former puts stormwater and wastewater elements in sequence, while the latter mixes stormwater and wastewater in a single set of pipes and is no longer permitted in the U.S. for new construction.

- Amenity value of wetlands is maximized by spreading them throughout the community; and
- Land for established wetland and ASR schemes can be found more readily in small distributed parcels rather than in fewer larger ones (Clark 1997, Section 5.2.1).

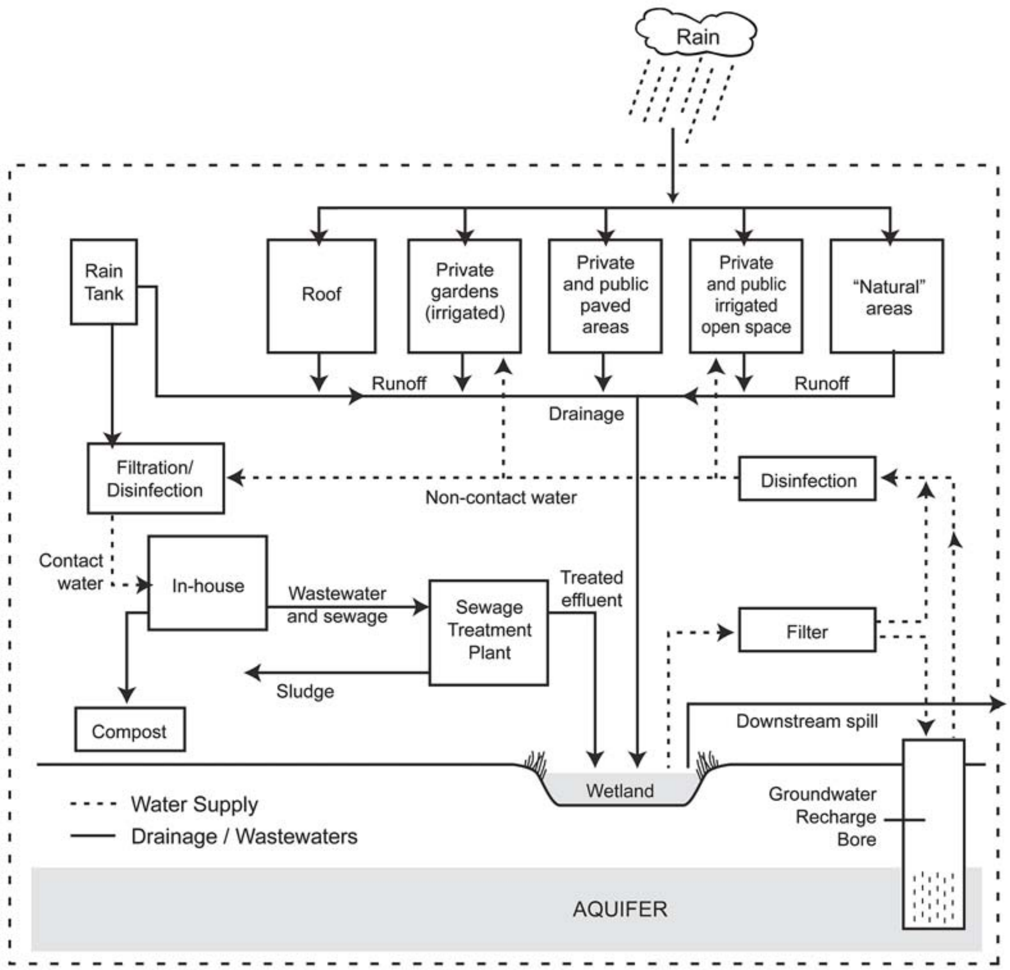

Figure 12-2: Integrated Water, Wastewater, and Drainage Scheme. *Source: Adapted from Clark (1997), Figure 5.2. Courtesy of Richard Clark.*

12.3 Nutrient harvesting

Decentralization benefit: *Decentralized systems allow for closer control of sources contributing to biosolids, which may provide benefits in improved biosolids quality. Further, new approaches to dry or ultra-low-water sanitation systems based on urine/feces separation offer opportunities for improved capture and use of nutrients in human waste.*

Biosolids management should not be seen just as a cost element (addressed in §11.4.5), but also as an opportunity to increase the sustainability of human/environmental systems. Recycling biosolids can "close the loop" for important nutrients in the normally linear path from farm to table to waste, or nutrients can be diverted to other important uses, such as reclamation of mining land and other disturbed sites. Small and decentralized systems offer the potential for separation of waste streams and monitoring/feedback on biosolids quality that may make the product of higher, known quality and thus more marketable.

In Sweden and Norway, farmers' organizations are very aware of chemical constituents in centralized wastewater treatment biosolids, and wish to avoid applying these potentially hazardous biosolids to the soil. In Sweden, starting in the fall of 1999, the farmers' union put a year-long moratorium on accepting sewage sludge on their fields, because of fears of heavy metals and halogenated compounds. Swedish treatment plants are landfilling or storing the sludge, and investigating installing or using incinerators. This is a cost associated with a system designed to take care of wastewater, without fully considering in what form the products will leave the technosphere and re-enter the biosphere, and who will be affected by this. Where septic tank sludge is treated in central wastewater treatment plants, this, too, is affected by the moratorium. Costs instituted by something like a farmers' moratorium are difficult to foresee but can be quite high if they occur. They can include landfilling fees, extra transportation, incineration fees, or even all the costs of designing, permitting, constructing, and operating a new incinerator. These costs may be avoided if the system is designed from the beginning to meet the needs of the end user, the farmer.

Feedback loops are important for the proper management of any system (Senge 1993). Small, decentralized systems offer feedback possibilities not available in larger systems. For instance, small industrial wastewater treatment systems with influent from only one company can make it possible to detect problems in the industrial processes that might go unnoticed if the wastewater were leaving the site untreated.

For example, the Cedar Grove Cheese factory in Plain, Wisconsin built a greenhouse-based sewage treatment plant for its effluent in 1998. Cedar Grove chose the 25 m^3/day (6,500 gal./day) facility as the most economical alternative available, but it also realized unexpected economic benefits. The greenhouse ecosystems are quickly and noticeably impaired when a spill of milk or whey gets in with the normal effluent. The crises in the wastewater treatment plant made the management of Cedar Grove much more aware of the number and quantity of spills of these valuable liquids. Each spill was quickly followed up by inquiries to find out what had caused it and what could be done to prevent similar accidents in the future. The savings in spills avoided are not possible to quantify precisely, but a clear trend of reduced numbers and quantities of spills is visible (Miller 2000; Wills 2000).

In centralized treatment systems, feedback loops are harder to come by. While some wastewater utilities employ sewage sleuths to track down the largest sources of heavy metals or other contaminants, it is not feasible to be aware of the contributions of each user. Small blackwater or urine-separating systems, on the other hand, lend themselves very well to preventing contamination of products to be land applied, as the tanks can be tested before collection. If the content of hazardous chemicals is too high, then the tank's contents may be rejected, and the user will have to pay a much higher fee for collection—perhaps even having it treated as hazardous waste (Skjelhaugen 1999). A similar system could be implemented for septic tank septage. To our knowledge, this sort of system has been proposed but never implemented anywhere. Institutional details including what tests to perform, how to perform them, whether to test all tanks or take random samples, and the costs of these measures need to be addressed.

A number of studies have been done in Sweden using life cycle assessment (LCA) to assess the environmental impact of nutrient recycling systems. LCA reveals many environmental costs that are incurred off-site, sometimes hundreds or thousands of miles away. For instance, LCA may address the benefits of not manufacturing the fertilizer that is replaced by use of nutrients from wastewater. While Tillman et al. (1996) did not find a substantial benefit from avoiding fertilizer manufacture, members of the same department worked with a refined methodology to find that replacing fertilizer manufacture did have a notable effect on the total environmental benefits of the nutrient recycling systems (Bengtsson et al. 1997). While the first proto-LCA study of wastewater treatment that the authors are aware of was done in the United States (Antonucci and Schaumburg 1975), it appears that study represents the only U.S. application of this methodology to assess the environmental benefits and costs of wastewater alternatives.

Feedback and assurance of biosolids quality may be a particularly interesting possibility of urine-separating and composting toilets. In Scandinavia, concerns about the sustainability of sanitation systems have led to a profusion of newly developed wastewater technologies in the last decade (Kløve et al. 1999; Staudenmann et al. 1996). A central design criterion for many of these technologies is returning the nutrients in wastewater to agriculture—from whence they came. The focus has largely been on the 5 kilograms of nitrogen and 1 kilogram of phosphorus that a human body discharges each year (Swedish EPA 1995). The costs and environmental impact of transporting these nutrients from where people live to agricultural land are a major concern, as they are contained in about 400 liters of urine and feces (*Ibid.*), before being diluted even further with toilet water. There has been a premium, then, in developing systems that minimize toilet water use, with collection of blackwater separate from its urine fraction, which contains most of the nutrients. In addition to the above references, some of the systems are described in Etnier et al. (1997) and Lange and Otterpohl (1991).

Etnier and Refsgaard (1998) have analyzed the costs and performances of these systems in rural areas, and found that nutrient recycling systems were the most effective in preventing pollution from nitrogen, phosphorus, and organic matter, and also the most cost-effective in most situations. By going beyond the annual cost of installing and operating a system, and looking at its effect in preventing pollution, it is possible to create a cost-effectiveness index. This type of index can be very useful to planners and regulators working in a watershed context.

Included in these calculations was the value of the urine and feces to the farmers spreading them. While the cost of the fertilizer replaced is relatively low (less than $5 per person annually at U.S. prices), it is a benefit that deserves to be highlighted. While sludge from wastewater treatment plants is often applied to agricultural land, it retains much less of the nitrogen than these decentralized, nutrient recycling systems. Blackwater treatment systems also retain much of the organic matter for reuse in agriculture, but the authors found no satisfactory way to set a value on the improvements in soil tilth.

12.4 Energy systems

Decentralization cost: *Decentralized systems do not provide the necessary control and scale to cost-effectively produce energy through sewage sludge digestion and combustion of the resulting methane.*

Biogas is produced at a number of centralized wastewater treatment plants and used to run turbines for electricity production or to provide plant or district heating. This is probably not an option or cost-effective for decentralized wastewater systems, with the small quantities of sludge they produce. Economies of scale would be lacking. It appears that cost-effectiveness (that is, the condition in which it is economic to produce energy from biosolids rather than purchasing it from an energy utility) requires wastewater flows of at least several million gallons per day (Tchobanoglous 2001).

12.5 Other opportunities

Decentralization consideration: *Additional opportunities for integration of wastewater and other systems may be favorable for decentralized systems, while others may be more appropriate for centralized systems.*

Other opportunities for infrastructure integration are possible:

- In Albuquerque, New Mexico, the city has run a fiber optic network connecting 19 buildings through sewer lines (Isaacs 2002). This practice could spread widely, especially in cities reluctant to dig up streets for installation of fiber (Jeyapalan 2002). Reportedly Japanese cities also use sewers in this way.
- Treated wastewater can be used as a heat transfer medium for district heating systems.
- In road widening projects, a large cost is for relocating public utilities. Decentralized systems with no or minimal collection systems running in street rights-of-way help communities avoid these costs. This has an additional benefit of reducing inter-utility competition for right of way space.

- Other beneficial wastewater treatment byproducts besides nutrients and energy may favor decentralized systems. For instance, greenhouse wastewater treatment systems (e.g. “Living Machines”) and treatment wetlands offer the possibility of harvests of useful plants. Some even have value as tourist attractions. One example is the Living Machine at the Ethel M Chocolate Company factory in Las Vegas, Nevada, which has become a key feature of the company’s site tours (Living Machines Inc. 2003).

13 Management

Decentralization consideration: *Management activities generally exhibit economies of scale, which can be attained either by centralized systems or "centralized management of decentralized systems." In some cases management requirements for decentralized systems are simpler and less costly than those for centralized systems.*

Management is the set of activities necessary to ensure a physical wastewater system (whether a single centralized plant or thousands of onsite systems) meets performance requirements. That is, management activities ensure a wastewater system is properly designed, constructed, operated, and maintained.

In the centralized wastewater field, typically a regulator oversees design and construction of facilities and tracks their performance, while a separate entity administers the system and provides O&M and other functions to run the facility (and collection system). Management is often inadequate in the centralized wastewater field, particularly for small wastewater systems. The U.S. Environmental Protection Agency has found many small systems have inadequate institutional capacity—often referred to as "TMF capacity," for "technical, managerial, and financial capacity"—and cannot properly operate and maintain their systems, or plan and budget for future upgrades and rehabilitation. This is often due to poor choices in wastewater system architecture—centralization of facilities in communities where decentralized systems would be adequate and typically simpler to operate and maintain.[58]

But the decentralized wastewater field has had its own struggles with management. Too often the regulator, typically a county or state health department, has only minimal responsibilities for tracking the performance of onsite systems after they are built, and O&M is left to homeowners and other entities with little capacity to ensure systems are kept up. This has led to many cases of decentralized system failure. As a result, the decentralized wastewater field has placed a considerable emphasis on developing policies, programs, guidelines, and institutions to ensure that decentralized systems are properly designed, constructed, operated, and maintained. Some management entities mainly focus on oversight, while others may be responsible for operation and maintenance.

This chapter focuses on the economics of proper management that ensures wastewater systems, centralized or decentralized, do not fail and create environmental and public health problems. The costs of failure are discussed in §14.4. Before addressing the economics of management, it is necessary to first understand the range of management institutions and management activities available for decentralized systems, since these may not be familiar to some readers.

Recently the U.S. Environmental Protection Agency developed a set of voluntary guidelines for decentralized management. The agency identified five "management models" for increasing management control as treatment system complexity and/or environment sensitivity increases, models that could be adopted by local governments, utilities, and other entities (U.S. Environmental Protection Agency 2003b, p. 5):

- *Management Model 1 - "Homeowner Awareness"* specifies appropriate program elements and activities where treatment systems are owned and operated by individual property owners in areas of low environmental sensitivity. This program is adequate where treatment technologies are limited to conventional systems that require little owner attention. To help ensure that timely maintenance is performed, the regulatory authority mails maintenance reminders to owners at appropriate intervals.

[58] Communities can "get in over their heads" with centralized systems. Bell (1997, pp. 21-22) recounts the story of a community that built a central plant to address failing onsite systems. The community then experienced a host of problems based on a poor treatment plant choice, inadequate planning for operational costs, and inadequate management capacity to deal with operational needs and problems.

- *Management Model 2 - "Maintenance Contracts"* specifies program elements and activities where more complex designs are employed to enhance the capacity of conventional systems to accept and treat wastewater. Because of treatment complexity, contracts with qualified technicians are needed to ensure proper and timely maintenance.
- *Management Model 3 - "Operating Permits"* specifies program elements and activities where sustained performance of treatment systems is critical to protect public health and water quality. Limited-term operating permits are issued to the owner and are renewable for another term if the owner demonstrates that the system is in compliance with the terms and conditions of the permit. Performance-based designs may be incorporated into programs with management controls at this level.
- *Management Model 4 - "Responsible Management Entity (RME) Operation and Maintenance"* specifies program elements and activities where frequent and highly reliable operation and maintenance of decentralized systems is required to ensure water resource protection in sensitive environments. Under this model, the operating permit is issued to an RME instead of the property owner to provide the needed assurance that the appropriate maintenance is performed.
- *Management Model 5 - "RME Ownership"* specifies that program elements and activities for treatment systems are owned, operated, and maintained by the RME, which removes the property owner from responsibility for the system. This program is analogous to central sewerage and provides the greatest assurance of system performance in the most sensitive of environments.

As far as the range of specific management activities is concerned, Table 13-1, pulled from the Environmental Protection Agency's draft management handbook, provides a good overview. Note, however, that this table does not include administration. Administration is the set of activities necessary to maintain an institution—a private company, a utility, a sanitation district, a local government public works department, etc.—that operates a wastewater system. Thus, administration includes accounting, billing, customer relations, management of staff, and other institution maintenance activities. Such activities should be included within the costs of management.

Table 13-1. Summary of Management Program Elements and Possible Activities

Program Element	Purpose	Basic Activities	Advanced Activities
Public education and participation	To maximize public involvement in the need for and implementation of the management program.	Provide public meetings, forums, updates, and education programs.	Provide public advisory groups, review groups, and other involvement opportunities in addition to basic program.
Planning	Consider regional and site conditions and impacts, long-term watershed, and public health protection.	Establish minimum lot sizes, surface/ground water setbacks and/or identify critical areas requiring more protection.	Monitor and model regional pollutant loads of different development scenarios; tailor development patterns and requirements to receiver site environmental conditions and technological capabilities.
Performance requirements	Link treatment standards and relative risk to health and water resource goals.	Prescribe acceptable site characteristics and/or system types allowed.	Require system performance to meet standards that consider water resource values, vulnerabilities, and risks.
Site evaluation	Assess site and relationship to other features.	Characterize landscape position, soils, ground & surface water location, size, and other site conditions.	Assess site and cumulative watershed impacts, ground water mounding potential, long-term specific pollutant trends, and cluster system potential.
Design	Ensure system is appropriate for site, watershed, and wastewater flow/strength.	Prescribe a limited number of acceptable designs for specific site conditions.	Implement requirements for developing alternative designs that meet performance requirements for each site, position in watershed, and wastewater flow/strength.
Construction	Ensure installation as designed; record as-built drawings.	Inspect installation prior to covering with soil and enter as-builts into record.	Provide supplemental training, certification & licensing programs; provide more comprehensive inspection of installations; verify & enter as-builts into record.
Operation and maintenance	Ensure systems perform as designed.	Initiate homeowner education/ reminder programs that promote regular O&M (pumping).	Require renewable, revocable operating permits with reporting requirements; verifiable responsibility for proper O&M activities.
Residuals management	Minimize health or environmental risks from residuals handling/dispersal.	Require compliance with federal and state residuals disposal codes.	Conduct analysis and oversight of residuals program; Web-based reporting and inspection of pumping and ultimate disposal facility activities.
Training and certification/licensing	Promote excellence in site evaluation, design, installation, and other service provider areas.	Recommend use of only state licensed/certified service providers.	Provide supplemental training and certification/licensing programs in addition to state programs; offer continuing education opportunities, and monitor performance through inspections.
Inspections and monitoring	Document proper service provider performance, functioning of systems, and environmental impacts.	Inspection prior to covering; inspections prior to property title transfer; complaint response.	Require regional surface and ground water monitoring; Web-based system and operational monitoring; required periodic operational & installation inspections.

Corrective actions and enforcement	Ensure timely return to compliance with applicable codes and performance requirements.	Complaint reporting under nuisance laws, inspection and prompt response procedures; penalties.	Denial and/or revocation of operating permit until compliance measures satisfied; set violation response protocol & legal response actions, including correction and liens against property by RME.
Record keeping, inventory, and reporting	Provide inventory development and maintenance for administrative, O&M, planning and reporting to oversight agencies.	Provide inventory information on all systems; performance reports to health agency as required.	Provide GIS-enabled, comprehensive inventories, including Web-based monitoring and O&M data for use in administration, O&M, compliance achievement and reporting activities.
Financial assistance and funding	Provide financial and legal support for management program.	Implement basic powers, revenue-generation and legal backup for a sustainable program.	Initiate monthly/quarterly service fees; cost-share or other repair/replacement program; full financial and legal support for management program; equitable revenue base and assistance programs; implementation of regular reviews and modifications.
Source: Draft Handbook for Management of Onsite and Clustered (Decentralized) Wastewater Treatment Systems (U.S. Environmental Protection Agency 2003a), Table 2-1.			

13.1 Costs of management

Management of a wastewater system usually benefits from economies of scale. Many key functions and personnel can be viewed as essentially fixed costs, invariant to the size of the system. It is precisely the inability to support these costs that results in the poor performance of many decentralized and small conventional systems, and economies and increased quality in administration and management are a frequent argument for the efficacy of centralized systems. However, ongoing efforts in the decentralized arena to develop institutional models that create economies of scale by consolidating administration and management (and many O&M functions as well) of multiple small and decentralized systems under one management authority should provide significant cost savings and improved management. English and Yeager (2002) provide a good discussion of how consolidation of responsibilities in a single "Responsible Management Entity" accesses economies of scale and increase the technical, financial, and managerial capacity available for management of wastewater systems within a larger decentralized system service area.

While it is clear that management costs show returns to scale, both for centralized systems and "centralized management of decentralized systems," information on the costs of management is still not well developed. Costs of administrative and management activities are often hard to distinguish because they are absorbed into other budgets, such as general staffing budgets. Also, management costs and O&M costs are often poorly distinguished; some entities separate the costs for these activities, others do not. For decentralized systems, it is clear that management costs for simple, soil-based systems (e.g., standard septic systems) are less than for systems that incorporate advanced treatment and mechanical components. Some of the better management cost figures in the decentralized system literature come from work by Karen Mancl of Ohio State University. For instance:

- The Lake Panorama Onsite Wastewater Management District in Iowa inspects onsite systems once every three years for full-time residents and once every six years for part-time residents. Once all systems were inventoried, the annual costs of the inspection program have been quite low. Inspections, record-keeping, meetings, and reporting required 0.4 FTE (full time equivalent) of staff time in 1998 for 676 inspections, at a cost to the District of about $30 per dwelling per year for salary, benefits, and transportation. The program has helped keep failure rates to about one percent per year (Mancl and Patterson 2001).

- The Will County, Illinois Health Department runs inspections and takes samples twice yearly of mechanical wastewater treatment systems (aerobic treatment systems) in the county. Management costs include salaries and support for two part-time sampler collectors/inspectors and administrative staff, and were estimated to run $50 to $60 per home for all 2,643 systems in the county in 1997. The program's cost also includes analysis of the samples, which is largely covered by a $100 annual fee charged to homeowners. Thus the overall management cost is somewhat over $150. Additional costs paid by homeowners that fall into the O&M cost category include $200 to $400 per year per home for a mandated contract with a maintenance contractor, plus $150 to $175 in tank pumping expenses (spread over more than one year) (Mancl and Vollmer 2001).
- Costs for management, including some O&M, were $100, $260, and $390 per year respectively for three additional management entities—Crystal Lakes, Colorado; Auburn Lake Trails, California; and Stinson Beach, California—studied by Mancl (2001b).
- Mancl puts the costs of semi-annual mound system inspections at about $100 to $150 per system per year, depending on local labor costs and travel distances (Mancl 2001a).
- For sand filter systems, Mancl puts the cost of semi-annual inspections at about $250 to $300 per system per year, again depending on local labor costs and travel distances (Mancl 2001a).

Another source of very rough management cost information is a survey undertaken in 2000 by Chase Environmental Services for the National Onsite Demonstration Program (Chase 2001). The survey asked 40 questions regarding demographics, onsite management systems, history and planning for the system, and future needs of local health departments, municipalities, townships, and utilities across the U.S. Of the 94 surveys sent out, 60 were returned. The responding entities served populations ranging from 20 to 500,000, with an average population of 41,578 and a median population of 18,000. A large majority of the respondents were local health departments (usually county entities), which may explain the large population served of some entities, which may include populations on sewer systems. Key findings regarding management costs were:

- The responding entities devoted an average of 5.56 FTEs to their onsite management program. On average, each FTE served about 5,860 residents and 1,807 onsite wastewater systems. These average figures may be skewed upward because of a few large entities that responded. Median staffing levels were 0.1 FTE administrative staff, 0.5 FTE clerical staff, and 1.4 FTEs professional staff, for a total of 2.0 FTEs (the actual median total is probably somewhat higher, but medians were not reported for several less prevalent staffing categories).
- Annual budgets of the responding entities averaged $168,000, or a median of $80,000. The survey author notes that some respondents may have reported the budgets of their entire organizations rather than onsite management programs only, or may have reported non-management activities. These could include system installations, maintenance, and repair, which 4, 12, and 6 entities, respectively, reported as services they provide.

Staffing and cost data for an entity that provides comprehensive management services but not O&M can be found in a case study of the Paradise, California Onsite Wastewater Management Zone completed by Pinkham, Magliaro, and Kinsley (2004). Paradise is a community of roughly 27,000 people located in the northern California foothills of the Sierra Nevada mountains. It lies on the east side of the Sacramento River valley, 90 miles north of Sacramento and 15 miles southeast of Chico. Most of Paradise lies on soils that are very suitable for wastewater soil absorption systems, and onsite systems have been used exclusively since the town's settlement. A sewer system was proposed in the early 1990s but rejected by citizens. Paradise had 11,324 onsite wastewater treatment systems as of November of 2002, making its Management Zone one of the largest onsite system management programs in the country.

An Onsite Wastewater Management Zone is a legal entity authorized under the California Water Code, Sections 31145-31149. It allows a community to implement its own management and enforcement program, thus assuming responsibility and accountability for the effective operation and maintenance of onsite systems within its jurisdiction.

As of mid-2003, the zone had three full-time and one part-time staff members. All were employees of a contractor, 7-H Technical Services, but operate out of town hall and represent themselves as town staff. In addition, the president of 7-H serves as the Paradise Onsite Sanitary Official, operating out of town hall one day per week. 7-H is responsible for essentially all functions related to managing the zone. Its services include:

- Review, prepare, and implement procedures for numerous types of permits, reviews, notices, etc.;
- Evaluate and approve or disapprove applications for wastewater systems;
- Track the results of onsite system inspections performed by private evaluators;
- Perform additional inspections of onsite systems as required to enforce town and state sanitation laws;
- Perform annual inspections of certain advanced systems;
- Represent the town in meetings with applicants and the general public;
- Respond to and answer complaints from the public regarding onsite systems;
- Perform sampling and analysis of surface and ground water stations twice a year;
- Review and assess quarterly and semiannual monitoring reports required of certain systems (as of August of 2002, there were 25 bottomless sand filters, 14 intermittent sand filters, 17 recirculating gravel filters, and 8 activated sludge package plants with nitrogen removal in the town);
- Operate and maintain any town-owned wastewater systems constructed during the five-year contract term (none had been built as of mid-2003);
- Confer with the Regional Water Quality Control Board and other professionals regarding wastewater systems and surface and ground water related matters within the town;
- Prepare monthly activity reports which are then submitted to town management and annual reports which are then submitted to the Regional Water Quality Control Board;
- Respond to emergency calls from the town public works director.

The 2002 fiscal year expenses for the zone totaled $284,968, of which $228,776 was for the 7-H contract. The difference represents allocated salaries and benefits for town staff (management, finance, and code enforcement); furniture and equipment purchases; debt service; depreciation; lab and permit fees; and miscellaneous office and operating expenses. The full budget amounts to just over $25 per onsite system per year. In addition, property owners pay about $65 to a private evaluator for a conventional system evaluation once every two to twelve years, with the frequency depending on site conditions, occupancy (owner or renter), and previous evaluation results.[59] Even including the evaluation costs, the costs of management in Paradise are considerably less than the costs reported by Mancl, for a management system that provides more comprehensive services than most. The low cost per system in Paradise probably

[59] The evaluation includes probing the septic tank to check for structural integrity and corrosion, measuring sludge and scum accumulation, performing a hydraulic load test, and conducting a surface inspection of the drainfield. Inspection and monitoring requirements for non-standard and advanced onsite systems are considerably greater and more costly, as noted in the discussion of O&M costs in §11.4.8.

reflects economies of scale for such a large program, particularly efficiencies in staffing. The zone is funded by an annual operating permit fee of $14.40 per residential customer (more for commercial customers) and additional fees ranging from $15.40 for a minor building clearance to $970.00 for an onsite rule variance application.

13.2 Benefits of management

Economic benefits of a management program accrued by both the individual property owners and the communities developing effective management, according to the U.S. Environmental Protection Agency (2003b), include:

- *Protection of property values.* There are many documented instances over the past few decades of property values increasing in areas formerly served by failing onsite systems after the area has been sewered. Management programs offer an opportunity to obtain the same level of service and aesthetics as sewered communities at a fraction of the cost, thus providing property appreciation and cost savings.
- *Preservation of tax base.* A well-managed onsite system will prevent small communities from having to finance the high cost of centralized sewers. Many small communities have exhausted their tax base, at the expense of other public safety and education programs, to pay for those sewers. Many communities then entice growth in an effort to pay for the systems, thus destroying the community structure that originally attracted residents.
- *Life-cycle cost savings.* There is a clear indication that in many cases management may pay for itself in terms of lower failure rates and alleviation of the need for premature system replacement; however, this will depend on the types of systems employed and the management program chosen. Documentation of that savings is only now being initiated.

In addition, management programs provide economic benefits by protecting public and environmental health and protecting a community's image (important to tourism and property values) from the damage that a health incident or environmental problem can bring.

13.3 Additional management-related economic considerations

Wastewater system management, particularly in the decentralized sector, is an evolving field. There is still a need for better information on the economics of management. A number of additional points relating to the economics of wastewater system management are worth noting here:

- Decentralized wastewater system owners often consider management an onerous imposition, and public oversight of private systems is a particularly sensitive issue (see §10.1 on convenience, intrusion, and other intangibles). Given these secondary costs of management programs, the ratios of benefits to costs for various levels of management are not clear. Certainly systems are needed to maintain a bottom line of environmental and public health protection. Communities should carefully consider how much management, and of what types, is necessary and cost-effective relative to their objectives and to meeting regulatory requirements.
- John Herring takes this argument further and predicts that increased management will not be widely adopted, given the absence of perceived benefits. He believes that onsite management districts will only be formed where one or more of the following special circumstances pertain (Herring 1996):
  - There is a serious threat to health or property values that a district might reduce at less expense than central sewers;
  - There is a widespread perception of a threat to public health or the environment and a perception that central sewers would be more expensive; or
  - The area is undergoing significant new development, so that district formation is a part of an overall development package.

- Management and system reliability, vulnerability, and resilience (see the next chapter) must be interrelated. The comparative costs of maintenance, the relative risks of breakdown, the costs and timing of major system repair, the effects on system reliability of various levels of management, and the relative risks from inaction for different wastewater treatment systems—onsite, cluster, and centralized—need to be better understood if communities are to make optimum wastewater system scale choices.
- Manpower quality is a crucial issue in management. In low-income rural areas, administrative and even some technical tasks are often allocated to minimum wage workers, who often cannot satisfactorily perform the necessary activities. Further, adequately trained personnel often move from poorly financed systems to pursue better opportunities elsewhere. These observations highlight the importance of attaining a "critical mass" of customers such that the requisite technical, managerial, and financial capacity is available. For instance, the entry of rural electric cooperatives into the decentralized wastewater field provides new opportunities to bring effective resources to bear on decentralized wastewater management.
- Decentralized systems may enjoy some advantages in administrative costs because they are rarely subject to the same monitoring and reporting burdens as point-source discharging centralized systems.
- Centralizing management of many diverse decentralized wastewater systems raises interesting questions of cost equity in the development and allocation of fees for management services. English and Yeager (2002) discuss these issues in a review of the practices of an RME, Steven's County Public Utility District, in the state of Washington.

14 Reliability, vulnerability, resilience

The information presented in this chapter could fit conceptually in several chapters. For instance, information about rates of breakdown could be presented in the O&M chapter, which could be structured to address relative reliability and the internal costs of failures; that is, costs to the managing entity. Impacts of failures on sites could be addressed in “Onsite and neighborhood impacts.” Exogenous sources of failures (vulnerabilities not tracing to O&M) and their impacts on communities and watersheds could be addressed in “Community and watershed impacts.” Some material could be dealt with in the management chapter. This report pulls these various issues into one chapter because “reliability” is a common and key concern of all stakeholders in wastewater management: property owners, communities, engineers, system managers, regulators, and so on. Giving it chapter-level treatment directly addresses those concerns. Further, discussions of “reliability” are often confused and conflated with related concepts that must be picked apart and carefully understood. Treating all these issues in one place will help the reader develop a better understanding of reliability and related issues. This discussion also sets a broad context for understanding issues in operations and maintenance, and in management, which are covered in other sections of this report.

Several definitions are necessary to clarify concepts related to wastewater system reliability:

> *Performance* refers to required or desired results of wastewater treatment systems: a level of nutrient removal, pathogen reduction or elimination, etc. Performance levels are often defined by regulatory effluent standards.
>
> *Reliability* is the rate or probability over time of attaining a performance level under a given set of operating conditions.[60]
>
> *Failure* occurs when a system does not meet desired performance levels. Typically the term is reserved for serious deviations from desired performance levels and not used for expected stochastic fluctuations outside of the desired performance range.
>
> *Vulnerability* is the susceptibility of a system to disruptions exogenous to those standard operating conditions.
>
> *Resilience* is the ability of a system to recover from disruptions or perturbations.

In reviewing the general implications of wastewater systems for reliability and related issues, one must consider whether a comparison of system architectures should be based on an assumption of good operation and maintenance, or on the actual historical evidence. There is considerable evidence that many onsite and cluster systems are not properly maintained, leading to poor performance and high rates of failure. This historical evidence is frequently used as an argument for sewering.

However, the same argument can be made against centralized systems. It is well-known that many small community centralized wastewater treatment systems are poorly maintained, leading to violations of water quality standards. Many larger centralized systems have chronic problems with sewer overflows owing to inadequate maintenance of sewers, including sewer laterals on private property, which typically contribute 50 percent or more of the total infiltration and inflow (I/I) to a system. Further, evidence is

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[60] The Metcalf & Eddy text explains: “Reliability of a treatment plant or treatment process may be defined as the probability of adequate performance for a specified period of time under specified conditions or, in terms of treatment-plant performance, the percent of the time that effluent concentrations meet specified permit requirements. For example, a treatment process with a reliability of 99 percent is expected to meet the performance requirements 99 percent of the time. For 1 percent of the time, or three to four times per year, the not-to-exceed daily permit limits would be expected to be exceeded (Metcalf & Eddy Inc. et al. 2003, p. 1636).”

mounting that conventional gravity collection systems have become a major environmental liability, releasing untreated wastewater into the ground across large areas (Amick and Burgess 2000).

Wastewater system planners should review the reliability aspects of different systems based on an assumption of proper operation, maintenance and management, and should specify the institutional arrangements necessary to ensure those activities are carried out and their costs are supported (see §13). As part of this effort, planners should consider whether the community can realistically support the proposed institutions and costs or is instead likely to fall into the historical patterns that lead to reduced performance and reliability.

Some additional discussion of the term "failure" is necessary here to set-up later discussions. It is important to understand the many implications and dimensions of wastewater system failure.

- There are two main classes of failures for wastewater systems. *Hydraulic failures* occur when a system is overloading by a quantity of wastewater outside of its designed capacity (e.g., sanitary sewer overflows, or SSOs), or when a system becomes stopped-up in some manner (e.g., clogging of the infiltrative surface of a wastewater soil absorption system), or develops leaks (e.g, exfiltration from cracked sewer pipes). In these cases untreated or poorly treated wastewater exits the system, typically where it is not supposed to (for instance, surfacing of water from a WSAS, or SSOs from manholes).[61] *Performance failures* occur when—for potentially many reasons—a system produces effluent for extended periods (beyond any expected stochastic deviations) that does not meet the desired level of performance. In such cases the treatment process is not functioning as expected.
- Failures may be highly visible (e.g., sewer system backups into basements) or invisible (e.g, leaking sewer lines, or onsite systems with malfunctioning treatment processes).
- The source or reason for failure can come from within the treatment system itself (poorly functioning treatment units, including those at or beyond their expected service lives), and from the system users (people pouring grease down drains), or it can be exogenous to the system (for example, flooding due to storms).
- Failures can be occasional and short-term (e.g., due to loss of electric power), or chronic and long-term (for instance, due to increased sewer I/I or faulty installation of an onsite WSAS).
- Failures have internal costs; that is, costs to the system owner or managing entity. And they can have external costs; that is, costs to adjacent property owners, communities, and the environment.
- Failures can vary widely in geographic extent, severity, time to fix, costs to fix, and additional characteristics.

The following sections address reliability, vulnerability, and resilience in further detail. The concepts of performance and failure are interwoven into these discussions. This chapter concludes with a review of the costs of wastewater system failure.

[61] Hydraulic failures create very direct risks by exposing people to pathogens in wastewater. When sewers or onsite systems cause backups into the home, the dangers also include longer-term problems such as growth of molds and fungi caused by, for example, wetting of a basement due to a sewer backup.

14.1 Reliability: routine achievement of expected performance

Decentralization consideration: *System reliability depends strongly on the inherent reliability of the chosen treatment processes and on proper operation and maintenance—factors that can vary with or be independent of system scale.*

Metcalf & Eddy et al. describe three sources of variability in wastewater treatment (Metcalf & Eddy Inc. et al. 2003, pp. 1636–40):

- Variability in influent flowrate and characteristics.
- Inherent variability in wastewater treatment processes.
- Variability caused by mechanical breakdown, design deficiencies, and operational problems.

Crites and Tchobanoglous (Crites and Tchobanoglous 1998) use the terms “inherent process reliability” and “mechanical process reliability” for the latter two sources of variability.

A certain degree of variability in influent flowrate and characteristics is usually addressed in treatment technology selection and design. Variability outside the expected range can also occur due to system misuse or exogenous disruptions. This topic is treated in the section below on resilience.

Regarding inherent process reliability, given influent flowrates and constituents within an expected range, every wastewater treatment process has a certain degree of variability in the quality of its output, owing to “the inherent variability of biological treatment processes due to the presence of living microorganisms and the laws of chance” and other factors such as design limitations (Metcalf & Eddy Inc. et al. 2003, pp. 1637–8). Treatment systems must be selected based on an understanding of the inherent process reliability of each option and how that variability matches with regulatory standards or other goals. Depending on the treatment process, inherent process reliability may or may not vary with treatment plant scale. Also, centralized and decentralized systems often use very different treatment processes, which of course will result in differences in their respective process reliabilities. The issue is further complicated because the performance standards against which the adequacy of a technology’s inherent process reliability must be judged are often different for centralized and decentralized technologies or plant sizes. A competent engineering analysis is required to determine which options, after accounting for design choices that affect the variability of effluent, have the necessary inherent process reliability to meet standards.

A key process factor for decentralized systems is that most use the environment as part of the treatment train. For instance, much of the treatment in a septic system occurs in the soil absorption field rather than the tank itself. Jones et al. (2001) highlight the importance of this aspect of decentralized systems:

> The spatial bounds of the engineering assessment for decentralized wastewater treatment systems differs from a typical engineering assessment because the environment becomes part of the system. That is, a drainfield or constructed wetland is an integral component of the treatment system, not just a part of the receiving environment. This may be disputed from a regulatory perspective, but from an engineering perspective, aeration, percolation, type of soils (e.g., clays, silts, or sand), water table levels, etc., can be as important to the engineering assessment as the actual dysfunction of the manufactured components of the system.

Variability in the environment utilized as part of a decentralized system treatment train introduces potential variability into the treatment process and its results.

The third source of variation in performance, mechanical process reliability, is a key concern for both centralized and decentralized systems, and is the main topic considered in this section. Wastewater treatment plants, centralized and decentralized, may have a variety of mechanical and other components that can fail, leading to failure of the system to achieve its required performance level.

From an engineering risk management perspective, to make appropriate system and process choices and to reduce chances of mechanical failure, a system planner or designer should have the following information:

- likely scenarios and time frames for failure, or breakdown in treatment capacity, for each of the technologies and/or designs being considered;
- routine maintenance schedules that would lower the risks of such failures in treatment of each system;
- costs of major repairs or replacement when failures do occur and costs of routine maintenance to prevent such failures;
- costs of installing and maintaining monitoring systems and benefits of information collected from them; and
- value (reduced failure risk vs. costs) of preventive maintenance and planned replacement of pumps, filter media, and other components.

As a general tendency, centralized systems tend to be mechanically more complicated than decentralized systems. As a result, they tend to require substantially more process monitoring and control, and maintenance, to maintain reliability. There are important exceptions. Wastewater treatment lagoons are very simple centralized treatment systems. They are arguably less complex than decentralized systems that use aerobic processes, particularly ones that include process controls to provide biological nitrogen removal. On the other hand, the small pumps used in certain decentralized technologies are extremely reliable.

It is generally understood that conventional septic systems typically require only routine maintenance, such as septic tank pumping, but advanced decentralized treatment systems are more prone to failure. The dominant risk management policy currently is the inspection by the county health agent or other regulatory personnel at the time the system is installed, before it is covered-up. Since many failures are attributed to flaws in system design and installation, this approach is well-timed to be a cost-effective element of risk management, if the inspection is thorough enough and carried out by a knowledgeable individual. In most states, ATUs and some other units also come with mandatory two-year inspection and maintenance requirements, again with the understanding that many of the failures occur within the first two years. However, the elements of the inspection and maintenance visits are often determined by the supplier of the equipment, and are often inadequate according to some decentralized system experts. Some communities and some states require long-term periodic inspection and maintenance programs for some systems, including the time of real estate transfer inspection approach. The preponderant long-run responsibility for onsite system inspection and maintenance, however, continues to rest with the homeowner.

Few good studies of failure rates and/or long-run performance of various decentralized technologies or designs are available, nor are causes of failures well-documented, in particular for technologies developed in the last five years. Minimally maintained advanced pre-treatment units generally have twice the failure rate of minimally maintained conventional septic systems (Gunn 1998; Ingram et al. 1994; Nelson et al. 2000; University of North Carolina Water Resources Research Institute 1992). However, specific definitions of failure differ among various studies.

To mitigate chances of failure, the decentralized wastewater field has in recent years emphasized the importance of management (oversight) of decentralized systems. A variety of institutional approaches to providing oversight, and sometimes O&M services as well, are available (see Chapter 13). The degree to which long-term professional inspection and maintenance programs would reduce risks to public health and the environment, and the costs of management both in dollars and in alienation of homeowners (§10.1) is still not clear, however. Conventional designs are conservative and able to withstand a certain amount of abuse and neglect. Homeowners typically repair hydraulic problems leading to sewage backup or surfacing. However, hydraulic failure is not always a sufficient indicator of system performance; a system may not adequately treat wastewater indefinitely. Thus, professional inspection and oversight of decentralized systems is advocated. Analysis of systems that are near sensitive surface waters or ground water, or that have mechanical and electrical components prone to failure, will likely show that the benefits of professional oversight exceed the costs.

Remote monitoring and control has the potential to reduce both the risks of treatment failure and the socioeconomic costs of professional maintenance, but technologies and approaches need to be examined (Tchobanoglous 1999). Anecdotal evidence indicates that remote monitoring can reduce the maintenance and repair costs for some systems, but it is not always clear what needs to be monitored and what system types give net returns on the investment in monitoring technology. Whether remote monitoring can reduce the political resistance of homeowners to maintenance programs is also a consideration.

A key factor in the reliability of both centralized and decentralized systems is the quality of the parts that are installed, and the quality of the installation. Cheap components and shoddy construction will compromise the long-term (and sometimes even the short-term) performance of any system. Sewer construction at the subdivision level is an area where developers and their contractors often "cut corners." This can affect centralized and cluster sewers alike. Treatment facilities can also be compromised by poor components and construction. Factors that can influence outcomes include:

- *Technology tests.* Some technologies are tested and proven in field use, others are only lab-tested.
- *Material tests.* On large projects, materials may be tested before installation or after installation but before additional construction steps take place.
- *Licensing of contractors.* Some jurisdictions license decentralized system maintenance contractors; others do not.
- *Testing of contractor competency.* Some jurisdictions test decentralized system maintenance contractors; others do not.
- *Inspection regimes.* Small and decentralized systems may get periodic, sporadic, or no inspections during construction. Some only get final inspections. The larger the management entity (which does not necessarily mean physical centralization), the more likely that it can staff inspection functions. Particularly large projects of centralized systems tend to have high-frequency inspections or even full-time on-the-job inspectors or project managers to oversee contractors.

Once construction is completed, maintaining reliability is partly an exercise in information management. Tracking maintenance activities and the condition of systems and components is key to maintaining and replacing them at times that are cost-effective and likely to ensure systems function properly.

In the centralized wastewater field, the ideas and practices of "asset management" have begun to gain attention as an approach to system reliability. Broadly, asset management is defined as "an integrative optimization process that enables a utility to determine how to minimize the life-cycle cost of owning and operating infrastructure assets while continuously delivering the service levels that customers desire (Association of Metropolitan Sewerage Agencies 2002)." Specifically, asset management sets performance goals or service level standards; develops comprehensive inventories of assets and their condition, often organized with geographic information systems (GIS) databases; and uses a variety of reliability analysis tools and costing techniques to analyze the asset inventory and focus maintenance and replacement activities on the most critical assets. Asset management is particularly useful for organizations that manage numerous, dispersed physical assets. Therefore, large wastewater utilities are rapidly taking up the tools, methods, and mindset of asset management to address the vast backlog of sewer system maintenance that troubles managers of most centralized wastewater systems.

The decentralized wastewater field is beginning to consider and adapt asset management to its particular concerns. Given that decentralized treatment systems are not unlike sewer systems in their widespread distribution, specific situational complexity (e.g., the influence of soil type on both sewer longevity and decentralized treatment system performance), variation in age and in technology, and variation in the consequences of failure, the asset management framework offers much that could be useful in the decentralized wastewater field.[62]

The National Decentralized Water Resources Capacity Development Project has sponsored a research and publication project that is developing a handbook on reliability analysis, within an asset management framework, for decentralized wastewater systems (Fane et al. 2004). The handbook will focus in particular on reliability analysis tools and costing tools useful to the decentralized wastewater field. It should be available from the NDWRCDP website (www.ndwrcdp.org) in early 2005.

14.2 Vulnerability: exogenous disruptions

***Decentralization consideration**: As a whole, decentralized systems may be somewhat less vulnerable to natural hazards and deliberate sabotage, but are perhaps more vulnerable to system misuse and inadvertent interference. Much depends on the particular technology, local conditions, and prevention and mitigation measures.*

Failures can be caused by disruptions that have nothing to do with system operation and maintenance. Systems that are more susceptible to exogenous disruptions can be considered “vulnerable” or “brittle.” Sources of disruption can include:

- Natural hazards
- System misuse
- Indirect and inadvertent human interference
- Deliberate sabotage

14.2.1 Natural hazards

Nature can wreak havoc on centralized and decentralized systems alike. Some examples and considerations include:

- Centralized treatment plants are often located in floodplains, as these locations are convenient for gravity transmission of sewage from communities and surface water disposal of treated effluent. In the “Great Flood” of 1993 in the Mississippi River basin, 109 treatment plants in the state of Missouri alone were impacted (Sanders 1997). Decentralized facilities are located close to homes and other facilities, which may or may not be located in floodplains. To the extent that decentralization keeps portions of a community’s wastewater flow from entering a flood-prone zone, compared to centralizing treatment in such a zone, the community’s wastewater system is less vulnerable to the impacts of flooding, which can cause damage that prevents proper plant operation for days or weeks. Decentralized systems in flood plains can of course be seriously impacted by flooding, sometimes requiring significant repairs (Anonymous 2000). Hazard mitigation measures taken before flood events can reduce vulnerability to and impacts of flooding (Noah 2000).
- Sewer lines that cross or follow streams and other drainages are vulnerable to wash-outs and cave-ins of surrounding soils, potentially causing loss of the pipe. Larger sewer systems may be more vulnerable, by virtue of crossing or running along more drainages. In Bluff, a small town in southeast Utah, citizens were very concerned about a centralized system proposal that including a pipeline

[62] A key difference is that centralized ownership of sewer assets provides an institutional context for cost optimization, while diverse ownership and diffuse responsibility for ensuring performance characterizes many decentralized wastewater systems, presenting cost optimization and decision making challenges.

crossing Cottonwood Wash, a drainage subject to flash floods, including ones that washed out a bridge in 1970 and severed a water supply line in 1994 (Stevenson 2000). Locating gravity sewers along streams can also make them susceptible from floodwaters entering manholes. Sewers can of course be buried deeply or armored, and manholes can be elevated above potential flood levels, but these measures add to the expense of sewer projects.

- Development may exacerbate flood hazards to wastewater systems, particularly to streamside sewers, due to increased peak flows as impervious surfaces increase within a watershed.
- Climate change is also likely to heighten vulnerability of wastewater systems. Most climate experts expect climate change to increase the frequency of large storms, their intensity, or both.

14.2.2 System misuse

Some systems are more vulnerable than others to misuse. For instance, onsite and small systems are more vulnerable to harmful actions by system users. Pouring petrochemicals and other substances down the drain can disrupt the microbiology of a wastewater treatment process. Larger systems are somewhat to substantially less vulnerable, depending on the increase in scale and the particular treatment technology, due to the diluting and buffering effects of greater wastewater flows. Homeowner education about the proper use of onsite and small systems is important.

14.2.3 Indirect and inadvertent human interference

People and their activities and infrastructure can impact wastewater systems indirectly or inadvertently. For example:

- Electric power outages can seriously disrupt wastewater systems, depending on the duration of the outage and the importance of power to the treatment process. For instance, activated sludge processes, at any scale, require power to supply oxygen that fuels aerobic treatment, and to move wastewater through the treatment chain. Other technologies require power only for the latter function, or not at all.
- Arcata, California chose its now-famous wetlands treatment system in part because a proposed regional solution required a pipeline across the bottom of a bay, and there were concerns that boat anchors could damage the pipeline, disrupting the wastewater system and bay ecology, and necessitating expensive repairs (Carol 1999, p. 10).
- In the city of Santa Cruz, California, a construction contractor ruptured a force main (Mill 2002).
- Well-meaning but poorly informed landscapers can do substantial damage to onsite systems and reserve soil absorption fields. Those who do not understand onsite systems or know their location may do harm by leveling mounded systems, putting irrigation systems in the wrong places, making bad choices for plantings near or on soil absorption fields, placing structures on current or reserve absorption fields, and so on (Chamberlain 2003).

14.2.4 Deliberate sabotage

Wastewater systems are potential targets for vandalism and even terrorism. Arguably, particularly with respect to terrorism, centralized systems are more tempting targets because of the larger impacts of compromising a large system.

The vulnerability of wastewater systems to vandalism and terrorism also depends on security measures. Since September 11th, 2001, authorities, trade associations, resource organizations, and utilities have given substantial attention to water and wastewater system security. For example:

- The U.S. EPA funded and the Association of Metropolitan Sewerage Agencies makes available the "Vulnerability Self Assessment Tool," or VSAT, a software package that helps water and wastewater utilities develop and update vulnerability assessments (http://www.amsa-cleanwater.org/advocacy/security/ and http://www.vsatusers.net/).
- The U.S. EPA has developed a series of guides to water and wastewater security products (http://www.epa.gov/safewater/watersecurity/guide/index.html).
- The National Environmental Training Center for Small Communities offers security training workshops across the country (http://www.nesc.wvu.edu/netcsc/netcsc_calendar.htm) and has developed a workbook entitled "Protecting Your Community's Assets: A Guide for Small Wastewater Systems."

These products also address vulnerabilities besides sabotage.

14.3 Resilience: recovery from disturbance

Decentralization consideration: *Diversity of treatment units, ease of repair, and other factors may make decentralized systems more resilient than centralized ones, but technology choices and local conditions will affect comparative resilience.*

Factors such as ease of repair, treatment process reaction to influent variability, and diversity of technologies within the overall system affect the ability of wastewater systems to recover from disturbances. Some considerations include:

- Repair of decentralized treatment systems may be simpler and quicker than repair of centralized systems. The latter may require more sophisticated or expensive equipment and expertise.
- As for collection systems, conventional centralized sewers are probably more time-consuming and costly to fix than alternative collection systems for the same reasons discussed in §11.2.1, which addresses the construction advantages of alternative, small-scale sewers. The centralized sewer disadvantage is obvious when compared to onsite systems, which have essentially no collection system.
- Much depends on the extent of disturbance. Disturbance to a large number of decentralized systems or across a large area may require more time and expense to repair. On the other hand, decentralized systems may be less vulnerable because they are geographically dispersed, so only a small portion of the total system might be affected.
- For decentralized systems, an important consideration is that private property owners will vary in their financial ability or their desire to effect quick repairs. Where systems are managed by entities other than the property owner, the thorny issue of access to private property for repairs arises. This is one of those issues that must be worked out in advance with easements, maintenance agreements, or other strategies if centralized management of decentralized systems is to be practical, economic, and effective.
- Diversity in decentralized treatment systems across an area may make the system as a whole less vulnerable to disruption, compared to choosing one technology by centralizing treatment. Such diversity could contribute to overall system resilience—for any given type of disturbance, some systems will bounce back quickly. Risks are mitigated by diversification.
- Substantial variability in wastewater flow rates and loading should be taken into account in the choice and design of treatment technologies. Some technologies are more resilient in the face of expected or unexpected variations than others. The classic problem occurs in communities with high seasonal population changes. Hydraulic and mass loadings can be much higher, for instance, during the tourist season than in the off-season. Some technologies, such as porous media biofilters (e.g. sand filters)

and constructed treatment wetlands, tend to deal with variability well. These technologies are often very appropriate and cost-effective at the cluster-system scale. Activated sludge processes, which are often used in centralized facilities, are considered more brittle and require more monitoring and adjustment to deal with flow and load variations. Unfortunately, some engineering firms are inclined to specify standard solutions for inappropriate situations. In Bluff, Utah, engineers originally proposed centralized treatment lagoons. This community sees a 10-fold increase in population from the winter to the peak summer tourist season. The adjustment the engineers proposed was to supplement wastewater flows in the winter with river water or culinary water from local wells, a dubious solution for a desert community (Stevenson 2000).

14.4 Costs of failure

Decentralization benefit: *On average, the risks and costs of wastewater system failure are probably less for decentralized systems than centralized systems, because the consequences of small, widely distributed failures are limited while the consequences of large, concentrated failures can be severe.*

The costs of wastewater system failures are potentially many:

- People can become sick from exposure to wastewater.
- Environmental harm may occur.
- Property values may be impacted.
- Property owners incur costs to repair or replace the failed system or system components.
- Businesses that had utilized the failed system(s) may lose income until repairs or replacements are completed.

For each of these major categories of costs, there are myriad variations. The costs may be both monetary and non-monetary. The full costs of wastewater system failures are rarely known.

When considering the potential costs of wastewater system failures—for instance, when making decisions about wastewater system options—it is often appropriate to use a risk assessment framework. Risk assessment "is the scientific (objective) process of estimating the likelihood and magnitude of adverse effects (Jones et al. 2001)." It is a formalized, structured process, separate from the management of risk. Some experts define risk as the probability of adverse events; others prefer to define risk as the probability of an adverse event multiplied by the consequences of the event (Stone Environmental Inc. 2004, p. 9).

In the decentralized wastewater field, a high-level framework for risk assessment has been developed by Jones et al. (2001). More recently, Jones and his colleagues have articulated a more detailed risk assessment framework for risk assessment of an onsite wastewater treatment system (report forthcoming from the National Decentralized Water Resources Capacity Development Project; see http://www.ndwrcdp.org/).

A comparative analysis of the risks associated with routine failures in centralized and decentralized systems would be useful. When a large sewer system suffers from SSOs or a treatment plant is flooded or otherwise breaks down, huge volumes of wastewater may be released to nearby surface waters. How do these risks compare to flooding/saturation of onsite wastewater soil absorption fields and to continuous breakdown of a small percentage of onsite systems scattered throughout the community? The consequences of the former are likely to be greater than the consequences of the latter. In the first case the volume can result in contamination of a large but single area, and can overwhelm natural and human systems within that area. In the second case, the area impacted will be small, at least initially, but the number of places impacted may be greater.

To the authors' knowledge, no such comparative risk assessments have been carried out. However, many people in the decentralized wastewater field believe that the risks posed by centralized system failures are greater than those posed by decentralized system failures. The harm, including deaths, caused by some notable centralized system failures, such as the cryptosporidium outbreak in Milwaukee, Wisconsin, seems much greater compared to known public health problems caused by decentralized systems. Lower-grade illnesses are believed to characterize health problems from onsite system failures, especially chronic performance failures.

Relative environmental harm from centralized and decentralized system failures is perhaps even more difficult to determine. While acute events tend to be very dangerous from a human health perspective, the environment has a remarkable ability to recover from acute pollution events, but in many cases is more susceptible to chronic contamination (e.g., eutrophication of water bodies due to long-term nutrient enrichment). However, such contamination can be an artifact of inadequate regulatory standards; for instance, allowing conventional septic systems in areas that should utilize some type of nutrient-removal technology. In such cases the problem is with the regulations, not the decentralized systems per se. The problem is not performance failure, but failure to perform—in other words, use of systems that cannot meet the standard that *should* be required—and the fault is with the regulations and not the technology.

In true cases of chronic hydraulic or performance failure—for instance, centralized system SSOs versus poorly maintained onsite aerobic treatment units—determining the greater harm is difficult. But that determination may again be moot. Wastewater system decisions should be made based on an assumption of proper operation and maintenance, in which case these sorts of failures should not occur. If they are likely to occur once chosen, something is fundamentally wrong with the planning process, or with regulations that force unsustainable choices.

15 Impacts beyond the watershed

Decentralization consideration: *The choice of wastewater system scale may contribute to costs and benefits realized at the county, state, or national levels. However, these broader implications—to subsidies and financial assistance criteria, regulatory costs, job generation, and greenhouse gases—are not well understood.*

Integrated wastewater planning primarily involves choices at the site, community, and watershed levels. The focus of this report is on issues that manifest at those levels. However, the choice of wastewater system scale can also have implications beyond the local or watershed level. Following are some of these implications. These are topics that have been raised in various discussions within the decentralized wastewater field in recent years. This study did not investigate these topics in any detail. The authors believe they have not received much attention. Therefore, they are offered here tentatively, as issues for further research. While consideration of these issues is not essential, and possibly not even useful, to current decision making at the local level, policy development and higher-level political decisions regarding these issues may eventually affect future choices and costs at the local or watershed level.

- *Subsidies and financial assistance criteria.* Centralized approaches benefited for years from the federal construction grants program for wastewater facilities. While major grants were phased out in the 1990s, subsidies for wastewater systems still occur through the low-interest loans of the Clean Water State Revolving Loan Fund (SRF). Some experts in the decentralized wastewater field believe that the lending policies and criteria of the SRFs of many states are biased towards centralized systems. Other loan programs, and some grant sources that are still available for wastewater infrastructure, may also be biased toward centralized systems, while some are targeted at small-scale (including decentralized) systems. As a matter of public policy, the question arises whether a) the available money, and b) the lending or grant-making criteria of financial assistance programs as currently implemented distort decision making and result in communities making inappropriate choices. A further question is whether publicly funded research in wastewater technologies and management gives adequate attention to decentralized options.
- *Regulatory costs.* It is unclear whether centralized or decentralized approaches require more regulatory oversight and compliance enforcement, and thereby impose a greater administrative cost on society. State and federal governments certainly have substantial programs set up to develop, monitor, and enforce policies and regulations governing conventional wastewater treatment and collection systems. On the decentralized side, substantial regulatory staffing occurs in county and state health departments that oversee onsite and small cluster systems. The costs of health department regulation of decentralized systems are difficult to determine because personnel and overhead are often shared by multiple health programs. An additional dimension is that new technologies, such as alternative onsite treatment systems developed by manufacturers, can require substantial review and approval effort.
- *Job generation.* Section 9.3 addressed whether spending on centralized or decentralized systems is more likely to support jobs and income in the local community. A different question is the gross job creation effect of wastewater investments across the nation. A 1992 study for the National Utility Contractors Association estimated that every $1 billion invested in water and wastewater infrastructure generates as many as 57,400 jobs (National Drinking Water Clearinghouse and National Small Flows Clearinghouse 1996). To the knowledge of the authors of this report, no similar study has been done for investments in onsite and small-scale systems. An additional issue is the effect of developing new wastewater technologies and services on the competitiveness of the United States in international markets, and resulting impacts on jobs in this country. The mainstream wastewater technology industry exports many of its products and services. Some manufacturers and consultants in the decentralized wastewater field also export their products and services. More such

exports could occur with further development of the field here in the United States, but it appears that some other countries, particularly in Europe, are "ahead of" the U.S. in this industrial sector.

- *Greenhouse gas contributions.* Many centralized facilities are investing significantly in nitrification/denitrification processes, which reduce nutrient loading to surface waters, but release considerable amounts of nitrous oxide, a greenhouse gas, into the atmosphere. Centralized nitrification/denitrification processes present an additional climate impact because they require large energy inputs. Burning of fossil fuels to produce the necessary electricity releases additional greenhouse gases. These nitrous oxide and power plant releases might be avoided by certain decentralized systems, especially those with low power requirements. An additional factor is that many types of wastewater treatment, across the range of scale, release methane, another greenhouse gas.

PART III – VALUATION: APPROACHES TO ESTIMATING BENEFITS AND COSTS

This section provides short descriptions of analytical techniques relevant to valuation of benefits and costs discussed in Part II. By *techniques*, this report means mainly analytical *concepts and methodologies*. Specific *tools* (e.g., models and software packages) are occasionally mentioned and sometimes briefly described as examples of implementations of the techniques. This chapter includes only tools that have been structured to address decentralized systems or decentralized and centralized systems. Many additional tools that address centralized systems only are available, but not discussed here. Further, a number of tools for modeling or otherwise evaluating biophysical implications of decentralized systems—for instance, for predicting nutrient loading from decentralized systems within a watershed—are available, but are not discussed here. See, e.g., Etnier et al. (2001) for a survey of some such tools. This section focuses only on techniques and tools directly applicable to economic evaluation of decentralized wastewater systems.

The objective here is to provide summaries of each technique, to economize on its description in the main text, since many techniques address more than one benefit or cost item. Specific features of each technique relevant to a particular benefit or cost item may be described in detail in the corresponding section of Part II.

16 Engineering economics

Engineering economics refers to the systematic treatment of cash flows (outlays and income) over time by applying mathematical formulae for the time value of money (see §8.1) to compare different cash flows on an equivalent basis. Within the financial analysis field, equivalent concepts and methods are known as "capital project valuation" or "capital project budgeting." A number of texts explain the concepts and illustrate the techniques in considerable detail (Ardalan 2000; Canada et al. 1996; Newnan et al. 2004; Peterson and Fabozzi 2002; Sullivan et al. 2003; Thuesen and Fabrycky 2001).

Many of the basic techniques, such as calculation of net present value or annualized cost, can be accomplished with a simple calculator, particularly a financial calculator. Standard spreadsheet programs such as Microsoft Excel provide functions for incorporating the time value of money into analyses.

17 Cost estimation tools

While engineering economics provides the necessary methods to include the time value of money in analyses of wastewater system investments and ongoing costs, cost estimation provides the data for the analyses. The term refers less to a technique and more to tools. Such tools are essentially databases of expected costs, usually as unit costs, for particular materials, labor, etc., based on costs from actual projects. Sometimes the data is provided as "cost curves" of either graphical or tabular form that show how costs per unit change with variation in the scale of a project or the number of units of an input purchased.

Various cost estimating databases are publicly available, the most well-known of which are the RSMeans guides, published by Reed Construction Data, which come in a variety of media and cover a wide range of industries at various levels of detail (http://www.rsmeans.com/). Many engineering firms have proprietary cost estimating databases that they use for client projects. These may include either or both decentralized and centralized systems depending on the usual project engagements of the firm. Often firms will build tools that integrate cost estimation data with methods that address the time value of money.

For the decentralized wastewater field, there are a few cost estimating tools that are publicly available. Several are briefly described below.

17.1 SANEX

SANEX is decision support software that aids planning and assessment of sanitation technologies for developing communities. The program is oriented toward developing country applications but may be useful to rural communities in industrialized countries as well. SANEX provides interactive menus for users to identify options and evaluate costs for their specific community needs and values via a "weighing" system. The software then screens out infeasible sanitation options and allows the user to compare remaining options for costs and performance. The Sanitation Compendium can be used in conjunction with SANEX or alone as a resource for information and illustrations of sanitation technologies. This includes cost models and an encyclopedia of sanitation technologies (Loetscher and Keller 2002).

SANEX version 2.0 runs on Windows 95, 98, ME, NT and 2000 systems but has not been tested for Windows XP. Dr. Thomas Leotscher developed the SANEX decision support software system at the Advanced Wastewater Management Center, University of Queensland, Australia. To obtain an updated version of the SANEX Software and/or the Sanitation Compendium, contact Dr. Leotscher (tloetscher@awmc.uq.edu.au) or visit http://www.awmc.uq.edu.au/manage/thomasl.htm.

17.2 WAWTTAR

The Water and Wastewater Treatment Technologies Appropriate for Reuse (WAWTTAR) program is a decision support tool to aid communities in effective and sustainable treatment and reuse planning. The WAWTTAR program has an extensive database that includes many alternative water and wastewater treatment options emphasizing water reuse. This tool is able to compare centralized and decentralized options for wastewater treatment and reuse as well as alternative collection systems. These capabilities are not available with most wastewater system cost estimation tools. This makes the tool particularly appropriate for small communities and tribes. WAWTTAR enables the user to identify public health standards, water resource requirements, resource availability, cost structures and ecological conditions of the community in editable data fields that WAWTTAR uses to screen technologies and estimate performance, construction costs and operation and maintenance costs. The U.S. Agency for International Development's Environmental Health Project (EHP) originally developed the WAWTTAR program in 1996. WAWTTAR requires an IBM-PC compatible computer with Windows 95 or higher (McGahey 1998). New versions of the program have been under development for the past several years at Humboldt State University, with funding from the U.S. EPA.

Copies of the WAWTTAR program can be obtained on CD by contacting John M. Gavin, U.S. AID Environmental Health Project, 1611 North Kent Street, Suite 300, Arlington VA 22209-2111 USA (telephone 703-247-8730; fax 703-243-9004; e-mail gavinjm@cdm.com) or directly from the developers at Humboldt State University by contacting Dr. Brad A. Finney, Environmental Resources Engineering, Humboldt State University Arcata, CA 95521 USA (telephone 707-826-3918; fax 707-826-3616; e-mail brad@gallatin.humboldt.edu), or Dr. Robert Gearheart, Environmental Resources Engineering, Humboldt State University, Arcata, CA 95521 USA (telephone 707-826-3136; fax 707-826-3616; e-mail rag2@humboldt.edu). An internet site for distribution of the program as well as documentation and training materials is planned.

17.3 COSMO

North Carolina State University has developed a predictive cost-estimation model called COSMO (Costs of Onsite Management Options), which can predict costs for 46 different combinations of pre-treatment options, distribution technologies, and other units which fit together in a treatment train, with varying loading rates, design flows, etc. Costs of equipment, materials, labor, etc. can be varied with local conditions and the characteristics of the site. The COSMO model includes precise schedules for various maintenance actions and planned replacements (e.g., media in filters). The model is currently in development and has only been used in a beta version. It is potentially useful to system designers, contractors, and policy makers. For further information, contact Mike Hoover at 919-515-7305, mike_hoover@ncsu.edu; or Mitch Renkow at 919-515-5179, mitch_renkow@ncsu.edu.

18 Approaches to considering uncertainty

Uncertainty is a fundamental issue in any evaluation of costs and benefits of proposed technologies or actions. As seen in §8.2, consideration of uncertainty is especially important with regards to financial risk. Many engineering economics textbooks (see references above) have sections on treatment of uncertainty within the deterministic framework of engineering economics. Here two approaches to uncertainty that are not typically covered in engineering economics are highlighted for the reader. These are **option theory** and **decision analysis**.

18.1 Option theory

Option theory helps one to recognize and value opportunities where “the range of potential outcomes presents an upside potential that can be quite high. The downside risk is only the cost of procuring the option, which is much more limited than the possible loss resulting from a sunk investment in an uncompetitive resource.” Capturing that spread yields “a ‘just in time’ resource commitment philosophy” in which “shorter lead time resources possess value beyond what is indicated by a standard calculation [i.e., net present value] because they allow a utility to wait for better information and thereby eliminate some uncertainty prior to commitment.” (Kaslow and Pindyck 1994)

Option theory is usually credited to Fischer Black and Myron Scholes (1973), who received the Noble Prize in economics for developing a theory and model to determine the value of financial instruments such as stock options. Subsequently, analysts such as Avinash Dixit and Robert Pindyck (1994) and Lenos Trigeorgis (1996) have developed concepts and models to apply option theory to analysis of alternative investment paths for real assets, including decisions to build or buy companies to enter an industry, decisions regarding the amount and timing of manufacturing or other physical capacity, and industry exit decisions. The fundamental concern of “real options” theory is to aid decision making where irreversible investments must be made under uncertainty about the future value of the investments.

Rigorous applications of real options theory to modular utility resources are few and early, but highly suggestive. The electric power industry has made some use of the technique. Because the technique has barely been applied to the wastewater industry, examples drawn from the electric power industry are useful here.

For example, Kaslow and Pindyck (1994) cite New England Power Company case studies in which, in certain specific circumstances,

- a resource with an option value is worth paying up to $167,500 more to acquire if lead time is one year but not if it is two years (*i.e.*, the flexibility of the shorter lead time is worth up to that much);
- a hydro repowering project, because of exogenous uncertainties, was worth $5 million more if deferred than if bought immediately;
- shutdown of two old, small coal-fired units should be deferred as long as economically possible to await better information on NO_x-emission upgrade requirements; and
- option theory was used to optimize buyout provisions in independent generators’ contracts.

A fuller case study is provided by a Harvard Business School paper (Teisberg 1994) that includes in its option pricing model of asset value

> ...descriptive factors frequently ignored,...including lead time, lumpy and sequential cost outlays, irreversibility of expenditures, and uncertainty about regulatory outcomes for completed projects. The analysis shows the value of shorter lead time technologies, the value of flexibility to delay or abandon construction, [and] the incentive to delay construction under uncertain regulation....

Under basic option valuation theory, "the value of an option increases as future uncertainty increases. Since exercise of the option is never required, managers are not forced to incur losses; however, they have the opportunity to take advantage of good outcomes by exercising the option if they choose" (*Ibid*.). That opportunity can be extremely valuable, because managers retain future choices, rather than being locked into one present choice and no future choices by the inflexibility of a large, lumpy, irreversible, long-lead time investment chosen now.

Option theory is well established and widely used. It uses, of necessity, certain idealized assumptions that may hide essential aspects of actual markets. But it is certainly better than the alternative of deterministically ignoring option values. Utilities can, after all, acquire tangible options to mitigate their risks. These options may include:

> ...(depending on the underlying resource) identifying sites, testing technologies, training installers, determining market potential, developing commercial relationships with suppliers, and perhaps reserving some generation or construction capacity. A small investment today may [ensure]...the availability of resources (existing generation, photovoltaic cells, accelerated DSM [demand side management], new central generation) in the future, at the time they turn out to be most valuable (Chernick 1994, p. 64).

Such valuable options are more likely to be bought if their option value is explicitly known.

Turning to wastewater management, Conrad and López (2001) have developed an option-pricing model for ranking investments to improve water quality. The model provides a closed-form solution for the optimal timing of an investment, relative to stochastic increase ("drift") in the concentrations of a pollutant and the attendant damage caused by this pollution. It also determines the value of an investment, for the case of two mutually exclusive alternatives. In the more realistic case where both projects are feasible and could be sequentially adopted, the authors develop a numerical analysis approach to combinations of adoption dates. The authors apply this approach to evaluation of a watershed management option for New York City's water supply, versus construction of a drinking water filtration plant. The watershed management option includes construction of local wastewater treatment plants in the water supply watershed, improvement of septic systems, improved handling of farm fertilizers and animal waste, and land conservation, all aimed at reducing nutrient and sediment inputs to the city water supply, which result in increased organics and increased chlorination disinfection byproducts that are harmful to human health. Filtration to remove the organics is the more infrastructure-intensive alternative. While this analysis and model do not directly address the questions of lumpy versus incremental approaches to infrastructure capacity (the watershed and filtration alternatives were each taken as total packages), it is instructive to analysts wishing to model the relative value of markedly different courses of action to protect water quality.

18.2 Decision analysis

Decision analysis explicitly describes all the key uncertainties and produces a flexible series of investment decisions that respond to the way uncertainties actually develop and resolve *over time* (as Peter Morris reminds us (1996), we don't learn the whole future in one year). This typically yields much better—more profitable or valuable—decisions than traditional methods. High returns to investment are more probable and low returns are much less probable, both at the cost of significant analytic effort. The technique has been successfully used in the electric power industry by the Northwest Power Planning Council, New England Electric System, and others.

In other words, as Resource Insight analyst Paul Chernick notes:

> Traditional approaches to reflecting uncertainty in utility planning, which essentially define a strategy as a fixed mix of resources, are too limited. A strategy includes options for responding to changing circumstances. Utilities should devise plans based not on simple expected values of future events, but on decision analysis by modeling a sequence of event, decision, event, decision. In more complex situations, Monte Carlo simulations, in which random events alternate with realistic utility reactions, can replace formal decision analysis.
>
> The lack of realism in the traditional resource-modeling process creates the impression of in-depth analysis without teaching the utility about the relative flexibility and risk-mitigating value of various resource plans and capability building. As a result, these approaches cannot reflect the major advantages of DSM [demand side management], renewable resources, and distributed generation over conventional supply: small increments, short lead time, security of continued supply, protection from fuel-price fluctuations, lack of environmental risk, and load-following in installation and operation. These methods also cannot reflect the advantages of 100-MW additions over 300-MW additions, determine the cost-effectiveness of building [combustion turbines]...with provisions for conversion to combined-cycle operation or coal gasification, determine the cost-effectiveness of pre-licensing potential additions to reduce lead time, or otherwise the costs and benefits of alternatives under uncertainty (Chernick 1994, p. 22).

In a particular site and a *well-characterized* set of circumstances, decision analysis can fully model the economic value of distributed resources' short lead times, small and modular units, and hence their ability to install exactly the amount of capacity where and when it is needed. How can this work in practice? Again, an example is available from the electric power industry.

A proprietary Electric Power Research Institute (EPRI) study (Morris et al. 1994) applied decision analysis to Pacific Gas and Electric Company's photovoltaic installation to reinforce the fully loaded Kerman substation. In that particular case, the flexible policy based on the modular resource and its ability to adapt to unfolding circumstances turned a large cost into a significant net benefit: The difference had a net present value equivalent to about one-eighth of the photovoltaic project's total value. If added (as it should be) to the separately evaluated other benefits of the project, this additional and previously uncounted benefit would rank fourth, just behind improved reliability, saved energy, and the avoided cost of upgrading the substation.

Unfortunately, no decision analysis of this or any other distributed-resource applications appears to be publicly available in full detail. It is a very active and profitable field for many consulting firms, which are naturally reluctant to make their methods, models, and findings public. But this example persuasively illustrates the important economic value of modularity, and of the flexibility it provides.

A final example akin to decision-theory valuation is offered by Hoff et al. (1997, pp. 33–34) who describe the hypothetical case of a developer who wants the utility to extend its grid to a greenfield site so he can build the first five of a planned 50-home development, but the utility isn't sure the project will succeed, so it's reluctant to pay $200,000 for the grid extension. On reasonable assumptions, the utility will lose an expected value of $45,000 if it extends the grid immediately. However, suppose instead it installs PV generation and storage for the first five houses, and then for five more houses if warranted. This gives the developer much greater confidence that the project will succeed. Only then would the developer commit to the grid extension for all 50 houses, and remove the original 10 PV systems for resale or reuse elsewhere, recovering ~95 percent of their value. This yields an expected gain of $72,000 in expected value. The difference between the expected value of these two strategies pays 59 percent of the grid-extension cost.

Conceivably a similar strategy could be used with the right type of decentralized wastewater treatment technology in areas where sewer extensions are planned but not imminent, though the value recovery for at least the soil absorption component of the system would no doubt be less. However, it should be noted that decision analysis requires considerable effort. It is probably only relevant to large wastewater utilities willing to look at decentralized systems as a component of major facility planning efforts, say, for an expanding peri-urban area.

19 Methods for economic valuation of non-market goods and services

Various economic techniques have been developed to measure the benefits and costs of goods and services that are not traded in price-making markets. Many of these techniques have been applied to estimating the value, in monetary terms, of natural resources (Dosi 2001; Freeman 2003; U.S. Environmental Protection Agency 2002a).

The values of natural resources are related to the goods and services they provide. Natural resource (or ecosystem or environmental) goods consist of the material outputs of natural systems (e.g., fish, fowl, timber, water, medicinal plants), while services are functional processes that provide benefits (e.g., wetlands may attenuate flood flows, recharge ground water, provide habitat for wildlife, and improve water quality by filtering or otherwise neutralizing pollutants).

Environmental goods and services contribute to peoples' welfare either in use or through non-use values. Use value is the value of human use of a resource, either directly, as in harvest and consumption of fish or fowl, or indirectly, as in avoidance of flood damages because of retention of water by upstream wetlands. Non-use value is the value people place on preserving a natural resource even though they have never visited it or used the goods or services generated by the resource. Non-use value includes benefits from: a) knowing the natural resource exists (existence value), b) preserving it for the use of future generations (bequest value), and/or c) retaining the option to use the resource in the future (option value).

Besides differentiating use and non-use values, a useful distinction can be drawn between public environmental goods and services and private environmental goods and services:

> Pure public services are those benefits flowing from a natural asset which can be enjoyed by one individual without detracting from the enjoyment opportunities still available to others… and which cannot be withheld, at a reasonable cost, by the "owner" of the natural asset under consideration. On the contrary, excludable environmental services which cannot be enjoyed by one individual without affecting the other individuals' enjoyment opportunities (from the same unit of service) are labeled pure private ones (Dosi 2001, p. 12).

Together, the concepts of direct and indirect use value, non-use value, and the public and private distinction provide a spectrum for valuation of environmental goods and services. On one end of the spectrum is direct use of private environmental goods and services. Such uses can be valued with market price and quantity data. Market valuation of standing timber provides an example. In the middle of the spectrum, indirect use of private or public environmental goods and services can be valued using a variety of demand-based and cost-based valuation techniques. Those most relevant to valuations attending wastewater decisions are discussed below. At the other end of the spectrum, the non-use benefits of public environment services can be quantified using the demand-based technique known as **contingent valuation**, which is discussed below as well.

19.1 Valuation using demand-based approaches

A major obstacle to valuing natural resources is the absence of markets that reveal demand for a good or service. To address this problem economists have developed innovative techniques using "surrogate markets"—markets for related goods and services or hypothetical markets—to estimate demand curves and associated values for non-market goods and services.

Surrogate markets can be used to estimate the public's willingness to pay (WTP) or willingness to accept compensation (WTA). Freeman explains the subtle difference between WTP and WTA as:

> WTP is the maximum sum of money the individual would be willing to pay rather than do without an increase in some good such as an environmental amenity…WTA is the minimum sum of money the individual would require to voluntarily forgo an improvement that otherwise would be experienced (Freeman 2003 p.9).

WTP and WTA measures are specific to the resource or benefit in question. For instance, an economist may want to estimate the public's WTP to protect or restore a natural environment. Conversely the analysis could focus on the public's WTA to allow environmental degradation. The concepts of WTP and WTA are flexible in that they can be defined based on the particular circumstance.

Demand-based approaches to valuation can be classified into two types: "revealed preference" and "stated preference." Revealed preference approaches use price and quantity data from markets that are related to the good or service of interest. The behaviors of consumers in the related markets are thought to reveal preferences (measured by WTP or WTA) with respect to the subject good or service. This information can be used to derive demand curves and values for the subject good or service. The valuation techniques that are based on revealed preferences are the **travel cost** method, the **random utility** method, and the **hedonic pricing** method. Stated preference approaches measure value by directly asking (surveying) consumers about their WTP or WTA for a non-market good or service. The **contingent valuation** method is an example of a stated preference technique. The following sections highlight the important aspects of these valuation techniques and provide specific examples.[63]

19.1.1 Travel cost method

The travel cost method is generally used to value recreational benefits at specific sites. Recreators incur costs to visit and enjoy a particular recreation area. Costs incurred by visitors include their time and associated travel expenses, such as gas, hotels, camping fees, fishing licenses and the like. The costs incurred by visitors are considered the implicit price paid for recreation at a particular site.

Using statistical methods, the travel cost method models the relationship between how often individuals visit a site and the expenses incurred on each visit. These expenses include the obvious such as gas and wear and tear on a vehicle. They also typically include travel time, valued as some fraction of wage earnings. An extension of the travel cost method is the site substitution method, which introduces into the model changes in the quality of the site. Statistical methods are used to approximate the relationship between the number of visits versus the costs and quality of the site. From the estimated model, the consumer surplus[64] associated with recreation at the site or the change in consumer surplus associated with site quality can be calculated. Statistical methods are used to approximate this relationship and an implicit price per site visitation can be derived from this approximation.

The advantage to using this method is that it mimics other empirically tested techniques. There are actual market transactions that can be observed to infer value. It is possible to then estimate the derived demand[65] for the resource in question using these observations of prices and quantities. Travel cost modeling is far less controversial than other surrogate market valuation techniques. Additionally, the

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[63] The following four sections draw heavily from material written by Booz Allen Hamilton Associate Lisa McDonald and first included in a report to the Southwest Florida Water Management District (Hazen and Sawyer P.C. 1996).

[64] Economists use consumer surplus as a measure of value consumers derive from a good or activity and to measure whether a consumer is made better or worse off by changes in the economic environment (Varian 1992, p. 160). Mansfield defines consumer surplus as a measure of the net benefit received by the consumer from the difference between what the consumer would be willing to pay and what the consumer actually pays (Mansfield 1994, p. 99).

[65] Derived demand is inferred from demand for a factor of production—a good or service necessary to produce another good or service that is sought by the consumer. In this example consumers are demanding a natural resource for its use as a recreational experience.

methodology can typically be applied at a reasonable cost. The disadvantage is that values must be derived from observable behavior, which means it cannot be used for many environmental goods and services. Technically, the estimated values apply only to individuals who visit the site, but value to the broader population can be inferred. The travel cost method is not capable of measuring non-use values. It is reasonable to assume that non-use values are a significant portion of the public's benefits from wetlands and other areas that could be damaged by wastewater system breakdowns.

For further reading on the travel cost method see Ward and Beal (2000) and Willis et al. (1999).

19.1.2 Random utility method

The random utility model is similar to the travel cost method and is often used to value recreation at a particular site. The difference is that random utility models focus on the choices individuals make among several sites. The technique is especially useful when substitutes are available. When employing the random utility model, the analyst will observe an individual's tradeoffs between sites with different characteristics. Observing the costs incurred at each site provides information on how individuals make tradeoffs between costs and unique characteristics. The information is used to estimate changes in consumer and producer surplus[66] associated with changes in the quality or quantity of a particular natural resource.

Value estimates derived from random utility models are considered to be an improvement over travel cost estimates because they consider the effect of substitutes on the economic value of a natural resource. The disadvantages are that the method is data intensive and cannot be used to estimate non-use values.

For additional reading on random utility models see Haab and McConnell (2002) and Bateman and Willis (1999).

19.1.3 Hedonic pricing method

The hedonic pricing model is another revealed preference methodology that estimates values of non-market goods and services from market data on goods and services whose value is partially determined by the existence and/or quality of the non-market good. Consumers purchase goods with a "bundle" of attributes. These attributes may include non-market goods such as clean air, clean water and aesthetic views. For example, to estimate the lost benefit of lower lake levels the real estate market associated with waterfront property is examined to determine the implicit price associated with the changes in water levels. Normally, this involves comparing market prices of similar properties except for differences in how lake levels affect aesthetics and other amenities. Examining how the quality of these non-market goods affects buyer and seller decisions to purchase the property reveals information on the value of the non-market good.

The advantage of using this technique is that the estimated benefit value is based on actual behavior. The disadvantage is that sufficient data may not be available, and an inability to measure non-use values. Also, consumers may not recognize and value subtle aspects of or changes in the environment. For instance, suppose there are subtle long-term health effects associated with the waterfront properties from the lower water levels but people are unaware of the causal link of these effects to the properties. If so, their willingness to pay to avoid the effects will not be reflected in housing price differences (Freeman 2003 p.393).

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[66] Producer surplus is analogous to consumer surplus but relates to the amount producers receive above and beyond the minimum price that would be required to get them to produce and sell units of a good or service (Mansfield 1994 p. 280).

Willis et al. (1999), Hidano (2002), Haab and McConnell (2002), and Garrod and Willis (1999) provide extensive discussion of hedonic pricing methods. Mahan (1997) illustrates application of the method to valuation of wetlands. Boyle and Kiel (2001) survey the use of hedonic studies in the water quality field.

19.1.4 Contingent valuation method

The contingent valuation method (CVM) uses differs from the methods discussed above in that it values non-market goods and services by directly asking individuals what their preferences would be in a hypothetical market. The dollar amount for a good or service obtained in a CVM survey is said to be contingent on the hypothetical market created by the analyst. A survey is designed to elicit from the respondents how much an individual might be willing to pay (WTP) or willing to accept (WTA) to just offset the relevant positive or negative economic welfare change (Bateman et al. 2003). The results of the survey are used to estimate changes in consumer and producer surplus associated with changes in the quantity or condition of an environmental good or service.

The contingent valuation method has been used extensively in non-market valuations because it is generally the only technique which measures both use and non-use values. It uses a carefully designed survey which provides the following: a) a detailed description of the issues surrounding the restoration program or environmental damage of interest, how the program will be implemented or the damage mitigated, and the end result of the program or the environmental good being valued; b) a method of payment for the program, e.g., through taxes, donation, or a utility bill charge; and c) a willingness to pay (or WTA) elicitation which may be through an open-ended question or a discrete choice format.

Surveys are conducted by phone, mail and/or in-person interviews. When programs are very complex in nature in-person interviews are preferred; however, this comes at a considerable expense. Some easily understood changes in environmental quality lend themselves to less expensive phone or mail surveys. A random sample is selected and surveys are conducted from this group. Statistical methods are then used to estimate the population's WTP or WTA for the restoration program or to avoid environmental damage.

There are two preferred methods for eliciting value from survey respondents. Under the Dichotomous Choice Elicitation Method, respondents are given the choice of hypothetically agreeing to pay a price, $K, to obtain the good (or service) being valued, or to forgo the good. If the respondent agrees to the hypothetical payment, then WTP lies in the interval, [$K,∞). The amount K is usually given several values; these values are randomly assigned to individual respondents.

Under the Double Bounded Dichotomous Choice Elicitation Method, respondents are first given the choice of hypothetically agreeing to pay $\$K_2$ to obtain the good being valued, or to forgo the good. Those that agree to paying $\$K_2$ are then asked if they would pay a higher amount $\$K_3$. Those that do not agree to paying $\$K_2$ are then asked if they would pay a lower amount $\$K_1$. This method allows placing individual willingness to pay in one of four intervals: $[0, \$K_1)$, $[\$K_1, \$K_2)$, $[\$K_2, \$K_3)$, $[\$K_3,\infty)$. The triplet (K_1, K_2, K_3) is usually given several values and then triplets are randomly assigned to individual respondents. This method is believed to be the most efficient elicitation method.

The survey responses are then statistically modeled. These models are then used to calculate changes in consumer surplus associated with an externality.

The most important advantages of CVM over the other methodologies previously discussed is CVM can elicit individual preferences on use and non-use values of natural resources. Stated in another way, CVM can be used to value many types of natural resources, benefits and damages even when market data do not exist. The main disadvantage of the CVM is that respondents may be unable to understand and articulate values for complex goods, such as those provided by the environment, in a way that mirrors what actual market behavior would be (Bateman et al. 2003).

The literature on CVM is voluminous. Bateman and Willis (1999), Bateman et al. (2002), and Haab and McConnell (2002) are good texts on the method. Within the wastewater field, Kofner (2001) proposes a contingent valuation study of the environmental management value and the open space value generated by cluster systems. McMahon et al. (2000) apply the method to estimating the benefits, in terms of household willingness to pay, of replacing unsatisfactory onsite systems with sewers in southeast England. McDonald and Johns (1999) apply the technique in an urban setting (Bogota, Columbia) to valuation of elimination of foul odors in the Bogota River, improved visual quality of the river, and elimination of public health problems from development of a primary and secondary wastewater treatment plant.

In efforts to gain more accurate environmental value estimates new versions of the Random Utility Model and CVM are beginning to combine revealed preference and stated preference techniques. These methods can be used to reveal attributes specifically not valued by market data, such as higher water quality or better fish catches and provide for comparison of stated and revealed preferences (Bateman et al. 2002). However, it is important to ensure the baseline characteristics across the RP and SP are the same or the preference structure may be inconsistent across the RP and SP responses (Haab and McConnell 2002).

19.2 Valuation using cost-based approaches

Demand-based approaches to non-market valuation are thought to provide the best value estimates because demand is based on willingness-to-pay, which indicates value. However, demand-based approaches often require costly data gathering efforts and sophisticated statistical analysis. Under certain conditions, costs related to environmental goods and services can provide a reasonable proxy of their value.[67] Cost-based approaches, while not giving “true” indications of human welfare and associated value, are often more practical than demand-based approaches. Cost-based techniques used to value non-market benefits associated with the environment include: a) **restoration cost**, b) **substitute cost**, c) **avoided cost**, and d) **defensive expenditures**. The following four sections highlight the important aspects of each technique and provide specific examples.

19.2.1 Restoration cost method

The restoration cost method values an environmental good or service by estimating the cost necessary to restore it if it has been or could be damaged. This method is often used in cost-benefit analyses of new projects and forms the basis of compensable damage assessment for public policies such as the Comprehensive Environmental Response, Compensation and Liability Act, CERCLA (Dosi 2001, citing Garrod and Willis 1999). This method may be used to measure the value of environmental change from restoring the environment to its original welfare state.[68]

The obvious advantage to using this method is its accepted use for public policies. The disadvantage to this method is it assumes that restoration costs do not exceed the economic value of the asset, which may not always be true. For example, if environmental substitutes are available, and can be acquired at a cheaper cost than the cost required to restore the damaged environmental asset, then the restoration cost method will provide an overestimation of the true value. Also, this method is unable to measure non-use values.

For additional reading on restoration cost methods see Dubgaard (2003). The restoration cost method is sometimes known as the replacement cost method (Garrod and Willis 1999, pp. 39-42), but note that “replacement cost” is also sometimes used to refer to the substitute cost method, discussed below.

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[67] The sections on each technique indicate some of the caveats. A general caveat to the use of this approach is that the costs in question must be borne voluntarily rather than required by an authority.

[68] Original welfare state in this sense means restoring a natural asset’s original service flow.

19.2.2 Substitute cost method

The substitute cost method estimates environmental service values based on the cost of providing substitute services. It uses market-priced costs of the least expensive substitute for the environmental service(s) to provide an estimate of the value of the environment or its services. For example the substitute cost method determines the value of wetland water quality services by estimating the cost of replacing those services with a wastewater treatment plant. This valuation method is also sometimes called the "next best alternative" method (Feather et al. 1995, p. 44), the "alternative cost" method (Young 1996, p. 40), or the "replacement cost method" (King et al. Undated).

The advantage to using this method is that it mimics other empirically tested techniques. The method provides measures of value for environmental services by means that are less data and resource intensive than demand-based market methods. Its disadvantages are: a) it can underestimate the value of the environmental resource since the goods or services for which a substitute is found likely represent only a portion of the full range of services provided by the environmental resource (Freeman 2003), b) it assumes substitutes provide the same benefits as natural resources, which is not always the case,[69] c) it may overestimate the value of the environmental resource if the substitute chosen for the valuation would not in fact be picked if the environmental good or service no longer existed, and d) this method is unable to assess non-use values.

For additional reading on the substitute cost method see Steiner's classic article (1965), Herfindahl (1974) and Young (1996, p. 102).

19.2.3 Avoided cost method

Also known as the damage cost method, the avoided cost method estimates the value of an environmental service as the costs that would be incurred if the service were not available. For instance, predicted flood damages to properties, in the absence of wetland water retention services, could be used to place a value on those services. Similarly, the storm protection service provided by barrier islands can be valued by estimating storm damage costs in the absence of the islands. Typically such valuations require modeling of physical changes in the environment (e.g. hydraulic modeling to predict flood stage changes in the absence of wetlands), a potential disadvantage.

For further information, a starting point is the extensive literature on using avoided/damage costs in valuation of flood control projects. For several references see Young (1996, p. 103). See also King et al. (Undated).

19.2.4 Defensive expenditures method

The defensive expenditures method can be easily confused with the avoided cost method. The difference is that the avoided cost method measures value by estimating the cost of hypothetical *damages*, while the defensive expenditures method uses actual or hypothetical costs to mitigate or prevent the effects of negative environmental changes to infer the value of environmental quality. Thus this method is also sometimes called the "averting behavior" method (Dosi 2001, p. 18). Statistical techniques are used to estimate effects of negative environmental changes by looking at the increase (or decrease) in averting expenditure to infer the value of decreasing (increasing) environmental quality (Dosi 2001). For example, individuals may avoid or reduce the health effects of increased water pollution by utilizing averting expediters such as spending energy to boil water, purchasing bottled water, or acquiring water treatment equipment. Or, returning to the example of storm damages, the defensive expenditure approach would look at the cost of storm walls or other engineered revetments designed to reduce storm damage.

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[69] Anglers may value wild salmon higher than stocked salmon (King et al. Undated).

The advantage to using this method is that it mimics other empirically tested techniques. There are actual market transactions that can be observed to infer value. It is possible to then estimate the derived demand for the resource in question using these observations of prices and quantities. However the defensive expenditures valuation method relies on three assumptions: a) environmental quality and averting expenditure are close substitutes, b) the environmental change completely explains the averting expenditures while not creating additional benefits, and c) averting expenditures are reversible (Dosi 2001). The disadvantages of this method is that these assumptions may not match reality, which can lead to underestimation or overestimation of the true values. Also, this technique cannot measure non-use values.

For additional reading on the defensive expenditures method see Hanley (1993) and Garrod and Willis (1999).

19.3 Valuation using "benefits transfer"

Sometimes estimating non-market values of ecosystem goods and services with demand-based or cost-based approaches can be complex and expensive relative to the degree of estimation accuracy required. To address this problem, economists utilize the "benefits transfer" approach to reduce study costs. Benefits transfer uses the results of original valuation studies at a "study site" to infer values for a different site, the "policy site."

This methodology works requires that the resources being evaluated are close in nature to those valued in the original study(ies). Values and results from the original studies are sometimes adjusted using statistical methods to account for differences in resource characteristics and the affected population. Benefits transfer studies are sometimes used by federal and state agencies to make preliminary assessments of projects or policies or to include an economic dimension along with other decision criteria.

The advantage to using the benefit transfer approach is that it costs less to perform than undertaking new research projects to determine values associated with every new project, regulatory change, or policy. The disadvantage to benefits transfer is that it is only as accurate as the quality of the original studies and the similarity of the goods and services (and their uses) at the original study sites to those at the policy site. Further, while the method relies on the seemingly straightforward concept of valuation by analogy, in practice substantial economic expertise is required to interpret the original studies and apply them properly to the policy site.

For additional information on the benefit transfer approach to valuation see Garrod and Willis (1999) and Desvousges et al. (1998).

20 Input-output analysis

Wassily Leontief, a Russian-born economist, is credited with creating the Input-Output model and field of analysis. In 1973 Leontief was awarded the Nobel Prize in Economic Science for his work. Input-Output models (I-O models) are used to predict positive or negative impacts on a regional economy caused from growth or decline of any particular industry sector. I-O models are constructed from community surveys of resource and labor inputs, and intermediate and final purchases in production and consumption activities. The data is then formulated into matrices for mathematical manipulation and analysis. The matrices determine inter-industry sector connections, changes in final demand, and multiplier effects (how much the economy will increase or decrease with one unit change in a given sector) (Miller et al. 1989).

I-O models examine both direct and secondary effects of changes in demand. Direct effects are changes in economic activity caused by first round spending; for example, when a tourist spends money in a particular region, thus increasing the money supply in the region. Secondary effects address subsequent rounds in re-spending first round dollars. There are two forms of secondary effects, indirect and induced. Indirect effects address ‘backward’ industry linkages; changes in sales, income, and or employment resulting from an increase or decrease in demand. For example, increased demand for home-building results in a backward link to an increase in demand for wastewater systems to serve the new residents. Induced effects are changes in demand from increases or decreases in the spending of income created by tourism or other industries that bring additional income into the economic region. Spending of this income affects demand for consumer goods and services, which in turn affects demand for the inputs of those goods and services, and increases (or decreases if there is a decrease in demand) income for the affected industries. Multipliers address the magnitude of secondary effects, expressing the linkages of industry sectors though ratios of sales and income changes to changes in direct sales (Wilcox and Harte 1997).

Input-Output analysis is not without its weaknesses. I-O models are static, accounting for the economy at a single given point in time – a definite limitation with a constantly changing economy. Many models also assume linearity of relationships from one industrial sector to another, and do not account for economies of scale (Wilcox and Harte 1997). Nonetheless, I-O models are widely used. Well known I-O software packages include IMPLAN Pro, REMI Policy Insight, and RIMS II.

IMPLAN Pro (IMPact analysis for PLANning Professional) is software that allows the user to construct an economic input-output analysis model for their particular region of interest. The program utilizes databases of 528 industrial sectors from the Bureau of Economic Analysis (BEA), Bureau of Labor Statistics (BLS), U.S. Census Bureau, and additional government sources to estimate the how changes in demand ripple through an economy. The IMPLAN system requires the purchase of both IMPLAN Pro software and IMPLAN databases separately. For more information about IMPLAN or to purchase the software and databases visit the Minnesota IMPLAN Group’s website, www.implan.com.

REMI Policy Insight (Regional Economic Models, Inc. Policy Insight) is economic modeling software that allows the user to forecast the effects of policy initiatives or new facilities on a regional economy. The model combines input-output matrices with an econometric module thus allowing the software to forecast effects. The REMI Policy Insight software is capable of estimating a wide range of impacts including policies and programs for economic development, transportation, infrastructure, environment, energy and natural resources, and state and local tax changes. For more information about REMI Policy Insight or to purchase the software, visit the REMI website, www. remi.com.

RIMS II (Regional Industrial Multiplier System II), an enhanced version of the original RIMS model, is a computer software program used for regional economic and industrial impact analysis. RIMS II has been used to estimate the impacts of local, state and national policy initiatives, opening or closing of firms, environmental impact analysis, and resource conservation. RIMS II derives its data from the BEA regional economic accounts, and BEA’s national I-O table, which provides the input-output structure of nearly 500 U.S. industries and 60 industry aggregations. The RIMS II software includes a series of multiplier tables for industries and industry aggregations for the region of study and a computer software program to view the tables. RIMS multiplier tables for additional regions of interest can be purchased separately. For more information about RIMS II or to purchase the software, visit the Regional Input-output Multipliers portion of Bureau of Economic Analysis website, http://www.bea.doc.gov/bea/regional/rims/.

References for further information about I-O analysis include Leontief (1986) and Miller et al. (1989).

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